World Sustainability Series

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Sustainable Agriculture and Food Security

Springer

World Sustainability Series

Series Editor

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Due to its scope and nature, sustainable development is a matter which is very interdisciplinary, and draws from knowledge and inputs from the social sciences and environmental sciences on the one hand, but also from physical sciences and arts on the other. As such, there is a perceived need to foster integrative approaches, whereby the combination of inputs from various fields may contribute to a better understanding of what sustainability is, and means to people. But despite the need for and the relevance of integrative approaches towards sustainable development, there is a paucity of literature which address matters related to sustainability in an integrated way.

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Sustainable Agriculture and Food Security

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Preface

The goal of sustainable agriculture is to save resources and protect the environment. This goal is also connected with another one, namely food security. This is because agricultural practices which are in line with the principles of sustainability not only lead with products with a greater quality, but often helps in ensuring their continuous availability.

It is not always appropriate to strictly relate "sustainable" with "organic"; conventional farms are also able to contribute to more sustainability in agriculture. Indeed, numerous farms and agriculture businesses have embarked on the path of consistent sustainability, with resource-conserving management and agricultural practices which are ecologically sound, ethically acceptable, socially just and also economically viable. This line of thinking suggests that sustainable agriculture produces high-quality food while conserving resources and the environment.

The goals of sustainable agriculture also are as follows:

(a) Maintaining and improving the productivity of soils.
(b) Minimising harmful impacts on climate, soil, water, air and biodiversity as well as human health.
(c) Using as few non-renewable and petroleum-based inputs as possible and replacing them with renewable ones.
(d) Working together with the local population and local stakeholders.

Also, it entails reliable employment with satisfactory incomes, good living and working conditions for all people working in agriculture and the strengthening of the agricultural sector to be less vulnerable to natural (e.g. climatic) and economic (e.g. high price volatility) risks.

There is, worldwide, a perceived need to promote sustainable agriculture and to, inter alia, foster the cause of food security.

Current food systems are currently associated with biodiversity loss, soil degradation, water pollution and climate change. The potential impacts of these environmental changes threaten the productivity of agriculture.

Therefore, in order to find suitable solutions in the sense of agro-ecological change, as many aspects as possible need to be taken into account. This ranges from the cultivation of food to processing and trade to the consumer and the respective political and social environment.

This book represents an attempt to foster the cause of agriculture and food security.

It is structured in two main parts:

The first part—Understanding climate change hazards: in this part, a variety of studies and technical assessments are showcased, aimed at leading to a better understanding of what climate hazards are and their implications.

The second part—Handling the impacts of climate hazards via adaptation methods and options: in Part Two, a wide range of experiences and case studies are presented, which illustrate the many ways via which climate hazards are being dealt with, along with the role of education and communication.

Thanks to its scope, this book not only provides essential scientific information, but also describes facts, trends and case studies from various geographical regions.

We thank the authors for sharing their knowledge and their experience by means of their chapters and those colleagues who have contributed to it by assisting with the reviews.

We hope this book will foster a broader understanding of the subject matter of sustainable agriculture, and how it is related to food security, supporting the search for suitable solutions for the problems seen in a central sector of the economy, and the basis of the livelihood of a considerable part of the population of our planet.

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Supporting Sustainable Agriculture

The Concept of Sustainable Agriculture

Jane Onuabuchi Munonye and Gladys Chinelo Eze

1 Introduction

The Sustainable development concept was conceived at UN Conference in Rio, Brazil in 1992 and has since been used as an economic and political guide for all sectors. At the same conference, it was also agreed that it is an essential goal for agriculture (Siebrecht 2020; Trabelsi et al. 2016). Sustainable agriculture, therefore, is the management system that conserves the natural resource base and uses technology as a means of accomplishing human needs and satisfaction both now and in the years to come. The subject of sustainable agriculture has generated great interest and debate in most parts of the world. Most farmers agree that the concept of sustainable agriculture is of paramount importance to the sustainability of the biosphere and it's ever-growing human population (Abubakar et al. 2013). Agricultural sustainability is a careful preservation and protection of natural and genetic resources that are eco-friendly and economically viable, socially acceptable and technically appropriate (FAO 1988).

Agricultural sustainability is envisioned as a condition where food is available to everyone without damage to the ecosystem now and in the future. Everyone needs to be involved: farmers, pastoralists, hunters, fishermen, foresters and rural settlers to actively get involved for economic development, job creation and work in a fair-price environment.

Sustainability is not only guarantees the continued use of natural resources, but also a beneficial and healthy environment, social and economic justice. Agricultural sustainability contributes to the four pillars of food security: availability, accessibility, use and stability. It also makes the environment responsible over time. Sustainability depends on environment and the impact on residents. The theory of Triple Bottom

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Line (TBL) emphasized the connectivity between the society (people), environment (earth) and the economy (profit). The challenge is for the public and private sectors to formulate a policy that could inculcate sustainability now and in the future (Kambewa 2007).

The growing world population needs food and other resources for existence and activity. Nevertheless, several constraints militates against the ability of agriculture to accomplish its mandate of food provision. These limitations include climate change. High biodiversity loss rate. Soil degradation due to soil erosion, consolidation, salinization and pollution. Depletion and pollution of water resources; rising production costs; declining number of farms and associated poverty, and declining rural population (Koohafkan et al. 2012). The way agriculture has been practiced over the years contributed largely to the above problems. (Ogaji 2005). Despite the constraints, the concept of agricultural sustainability has continued to be conspicuous since Brundtland Report in 1987 (Tait and Morris 2000).

The earth's ecosystem, environment, and humans have been reshaped since the dawn of agriculture. Agriculture is the only mechanism that directly makes use of natural resources and technology and transforms them into product and services for immediate and future use; taking into consideration economic, social and environmental factors, Fig. 1. These products are used now for human satisfaction. But over time, the complete dependence on natural resources has depleted the biodiversity and ecosystem. This has raised doubts about how sustainable the environment will be in the future. The apprehension of this and the next generation's wellbeing has become a concern. The UN and countries of the world have worked for some decades towards

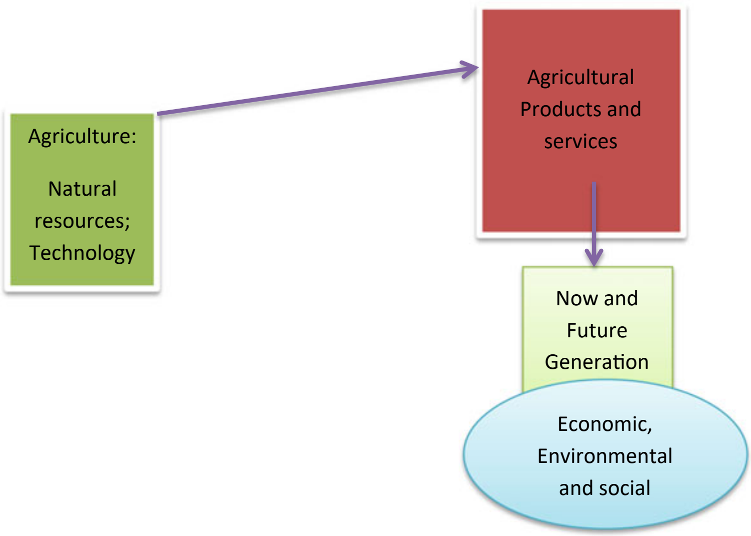

Fig. 1 The concept

sustainability, and agriculture has been an integral part. The following objectives guided the study:

- Examination of the theory and principles of sustainability about agriculture
- Examination of the need to be sustainable in agriculture
- Identification of the way forward.

2 Empirical Evidence

The empirical evidence in the concept of sustainable agriculture study is from secondary sources. These sources include: examination of the theory and principles of sustainability; the need to be sustainable, and the way forward.

2.1 Theory and Principles of Agricultural Sustainability

Some concepts relate to the sustainability of a particular economic sector and relate to some functional areas. For agriculture, there are Sustainable Agriculture and Rural Development (SARD) and Multifunctional Rural Development (MRD).

The first concept of SARD was developed at a conference hosted by the Food and Agriculture Organization (FAO) in Rome (FAO 1989). It is rural development facilitated by the introduction of technological and institutional changes that makes it possible to meet the needs of current and future generations. The 1992 Rio Declaration and Agenda 21 later introduced SARD. The main priorities are: Food security. Good working conditions for farmers, decent living, and protection of natural resources.

SARD is a very broad concept. It covers all the three aspects of sustainable development, social ecological, and economic (Fig. 2). Includes goals for well-being, food security and environmental protection (Kociszewski 2018).

RD also appeared in Agenda 21 of the Rio Declaration. It is a process that involves the following functions in the rural areas: social (culture, employment, and service), ecology preservation of biodiversity, water), production, provision of infrastructure and tourism (Kociszewski 2015).

It is important to note that MRD is not solely for agricultural production but could have an impact on sustainable development (SD). An interaction of productive, economic, social, cultural and environmental factors are designated as multifunctional agricultural system (Wilkin 2010). It cannot exist without the production of food and raw materials.

These concepts of SARD and MRD cannot, thus, exist without agricultural production. The UN-SDGs emphasize accountability for now, and in the future, on how these concepts are carried out.

Table 1 shows the five principles of sustainable agriculture. The five principles of sustainable agriculture are outlined in Table 1. These five principles, with policy

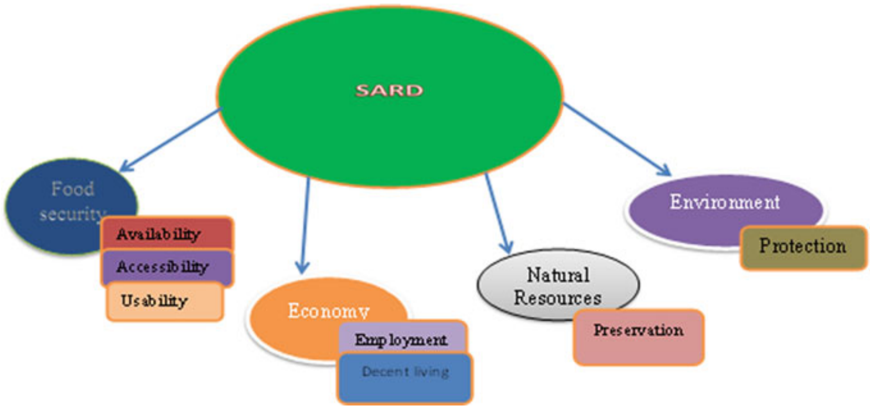

Fig. 2 The four stands of SARD

implications, are discussed in relation to aquaculture, crops, fisheries, forestry, and livestock production.

2.2 The Need to Be Agriculturally Sustainable

Agriculture produced an average of 223.7 million tonnes of food. Grains, roots, tubers, fruits and vegetables made 19.5 million tonnes, meat 1.1 million tonnes and 2.1 billion litres of milk (FAO 2012a). Daily harvests from fishing and aquaculture accounted for over 400,000 tonnes of fish. Forest products provided 9.5 million cubic meters of timber and firewood. 7.4 trillion Litres of water and 300,000 tonnes of fertilizer were used to grow and irrigate plants (FAO 2013a; FAOSTAT 2013). Agriculture secures the livelihoods of approximately 2.5 billion rural households' meets human needs for food, textiles and fuels (FAO 2013a). It contributed to the social cohesion of rural areas and protection of cultural traditions and heritage (Van Huylenbroeck et al. 2007).Agriculture is misunderstood, but it makes an important contribution to landscape and wildlife management. It also helps in wildlife conservation, water management. Flood, and climate protection. The world's population of 7.2 billion is estimated to be 9.3 billion by 2050 (United Nations 2013). Expected dietary changes associated with population growth and income growth means that agriculture must produce 60% of food by 2050.100% more in a developing countries.

Technology and innovative advancement had made agriculture grow. Furthermore, more and more lands were put into use and family lands were consolidated into megafarms. The Green Revolution has increased grain production in South Asia by more than 50% through the use of high yielding seeds and improved technology. World agricultural production has tripled in 50 years and cultivated area has increased by, only 12%. By strengthening agriculture, farmers can feed the world, but also save millions of hectares of forest from conversion to farmland and unquantifiable

Table 1 Principles of agricultural sustainability

Principles	Policy applications				
	Aquaculture	Crops	Fisheries	Forestry	Livestock
1. Resource management efficiency is important for sustainable agriculture	Improved aquaculture management through good feed regime, robust biodiversity and animal health; good management practices; domestication of different species, animal welfare and implementation of ecosystem approach)	Using different genetically modified varieties of crop and proper application of both organic and inorganic fertilizers and better soil moisture management procedures, moist and pest management and precision agriculture	Improved efficiency in fuel use, fishing costs and waste management	Efficiency in management of natural and man-made forest resources through reduction in deforestation and increase in renewable energy and forest products	Use of genetically improved breed, balanced ration and health management
2. Conservation and protection is a requirement for sustainable Agriculture	Conserve and promote to ensure diversified ecosystem approach	Using better practices in soil, water and biodiversity management; considering environmental requirement and policy implications	Protection of natural resources habitats by building dams and efficient ecosystem management and observing existing fishing laws	Efficient conservation of forest and products to enhance soil water conservation and landscape	Conservation of improved livestock, reduce pollution and less intense production

(continued)

Table 1 (continued)

Principles	Policy applications				
	Aquaculture	Crops	Fisheries	Forestry	Livestock
3. Protection and improvement of rural livelihood, equity and social well-being	Improve small scale producers through provision of infrastructure, gender balance and using ecosystem approach	Protection of farmers from land tenure, credit, market access and rural nutrition	Improve access to land, market and promotion of small/medium enterprises. Integration of fisheries in reduction/alleviation plans	Promotion of local stakeholders and women to access forest resources and employment	Improve infrastructure and increase opportunities for small and medium enterprises to increase nutrition
4. Increase resilience of communities and ecosystems	Risk assessment and early warning preparedness	Risk assessment, communication, climate change awareness and natural disaster warning	Risk assessment, communication, multipurpose industry and value chain. Preparation for climate variability and safety nets	Enhance resilience of ecosystem to hazards including climate change. Prevention of cross border transmission of pathogen and risk management strategies and introduction of land use planning	Risk assessment, communication and climate change awareness. Quick response to market volatility, production and savings

(continued)

Table 1 (continued)

Principles	Policy applications				
	Aquaculture	Crops	Fisheries	Forestry	Livestock
5. Good governance mechanism; a requirement for sustainable food and agriculture	Adherence to institutional standards. MPs, GAPs and maintenance of ecosystem	Formation of association, participation of stakeholders	Local communities capacity empowerment, governance and decision making and participation of stakeholders	Understanding of the benefit, conflict resolution and equitable distribution of benefits of forest	Develop decentralized capacity through effective participation; formation of association and consultation

FAO (2014)

ecosystem services, by so doing, an estimated 590 billion tonnes of air pollutant could be avoided.

Though productivity had increased, agricultural performance did not assure future returns. The previous production pattern was not sustainable. Although supply had increased, agricultural production still impacted negatively on the ecosystem. The majority of the rural population resides in rural areas and depends solely on natural resources for survival. With over-exploitation by growth companies in natural resource use; there was a mass exodus to the urban areas and extinction of environmental biodiversity. Without good governance, degradation, inequalities, and conflicts of interest prevail.

The institutions and policies underpin the world's food security and agricultural production systems were grossly insufficient. The world's food systems has been heading for an unprecedented confluence of pressure over the next 40 years (Foresight UK 2011). Unless the trend is reversed, it will affect the long-term global food production capacity and the economic benefits needed for food security. Global population kept increasing by the minute and the present food production and distribution systems are inadequate to support a teeming population. Dietary malnutrition in one-third of the population of developing countries can, in severe cases, lead to intellectual disability, blindness and eventually death. On the other hand, 1.5 billion adults were overweight or obese and were at increased risk of developing non-communicable diseases, due to overdose of cheap, high-energy, and low-nutrient foods (FAO 2012b).

More so, huge financial and environmental resources have been spent on producing food that is lost or wasted at home along the value chain. Food losses and waste implies malfunction food systems, representing careless utilization of natural resources and environmental carbon discharge (FAO 2012c). FAO predicts that 80% of the additional food needed to be food–sufficient by 2050 come from land already cultivation land. Except for Africa and South America, expansion of agricultural area is limited. Most of the additional land is unsuitable for husbandry. The reason is due to environment, way of life of the people and the economy. Bringing such areas into production will be very costly. Since the beginning of this century, drought and desertification have lost about 12 million hectares (UNCDD 2013).

FAO and JRC (2012) stipulated that 13 million hectares of forest have been converted to other forms of land use. Primarily, agriculture costs huge amounts of money for ecosystem services.

The details of major concerns highlighted are shown below:

- **Water Usage and Pollution**

Over dependence of agriculture on world's freshwater resources unsustainable. Inefficient use of water for plant and animal production has depleted aquifers, reduced river flows, adversely affected wildlife habitats and resulted in 20% salt damage to the world's irrigated lands (FAO 2014). Poor application of both organic and inorganic fertilizers and pesticides caused water pollution. By 2025, 1.8 billion people are projected to live in countries with absolute water scarcity, and two-thirds of the world's population could live under condition of water scarcity (Viala 2008).

Water consumption has doubled due to population growth and the proportion of water used by agriculture can be significantly affected. Most of the fishery caught comes from coastal waters, and pollution can have a serious impact on productivity and quality.

Agricultural production is water dependent and could be susceptible to water risks. It uses water more than other sectors of the economy. Agriculture is exposed to widespread and growing water scarcity. Deep waters in Chile and the United States have reduced surface and groundwater, with serious implications for husbandry (OECD 2021).

To facilitate a more sustainable and productive agricultural sector; government intervention would be required on the farm and wetlands at both local and national levels to strengthen and enforce water regulation; providing incentive to farmers to improve their water use and pollution reduction and discard polices that support excessive water use.

These challenges will undermine the efficiency of rainwater and irrigated crops and livestock activities. Irrigated agriculture accounts for 70% of world's water consumption and more than 40% in Organization for Economic Co-operation and Development countries (OECD 2021).

- **Change in Climate**

Climate change is the greatest environmental challenge facing humankind, and the agriculture's contribution to greenhouse gas emissions is high. Climate change is expected to make extreme weather events such as floods and tropical storms more common. Climate change is expected to increase precipitation and surface water volatility, reduce snow cover, and affect plant water demand. Most of the world's greenhouse gas emissions are directly driven by plant and animal production and forestry, especially deforestation (IPPC 2014). An additional 2% of emissions come from fertilisers, herbicides, pesticides application, and energy consumption for farming and irrigation. Intensive husbandry causes the loss carbon in the soil. About 80 tonnes per hectare, most of which is released into the atmosphere (Lal 2004). Agricultural production is vulnerable to climate change-raising temperatures, pests and diseases, water shortages, extreme weather events, and exhausted biodiversity.

- In tropical regions, where the majority of the world's food insecure and undernourished lives, plant production can be insufficient. Yields in Asia Africa will fall by 8% by 2050. Climate change also increases market volatility and affects most people already at risk (Wheeler and Von Braun 2013). The negative impact of climate on husbandry can only be partially overcome by adaptation measures (IPCC 2014).**Poverty, inequalities, hunger and malnutrition**

In recent times, food production and distribution systems have not been adequate to feed the world's population. Global hunger trends, as measured by the prevalence of malnutrition over the last three years, have fallen to levels of less than 11%. Meanwhile, the number of hungry people has slowly increased; coupled with the hidden hunger component. As a result, more than 820 million people worldwide became hungry as at 2019. This underscores the immense challenges of achieving the Zero-Hunger Goal by 2030 (SDG 2) (FAO 2019). Hunger is increasing, especially in, Africa, the Caribbean and Asia with the highest prevalence of malnutrition in the population at 20%, 7%, and 12%, respectively. The latest trends are also in global serious food insecurity estimates based on the Food Insecurity Experience Scale (FIES), which is another indicator used to monitor hunger (FAO 2019). In 2013, husbandry produced enough food for 12–14 billion people, but 850 million, or one in eight of the world's population, lived with habitual hunger (FAO 2013b). Hunger was mostly found in developing regions of the world, with malnutrition estimated at 14.3% (IFAD, and WFP 2013). The cause of hunger and malnutrition was not the lack of food availability, but the affordability. Ability to pay. For example in 2010, more than one-third of the rural population of developing countries was" very poor" (FAO 2013b). 60% of women are malnourished, 43% are engaged in agriculture, and they are discriminated against in access to land and other resources (Asian Development Bank 2013).

- **Poor diets and unsustainable consumption patterns**

Lack of balanced diet, lacking in essential nutrients—proteins and vitamins and minerals had made developing countries to suffer from micronutrients deficiencies which could in extreme cases lead to mental disability, blindness and ultimately premature death. Excessive consumption of cheap, high-energy, nutritious foods can make more than 1.5 million adults obese or overweight and susceptible to non-communicable diseases (FAO 2012b). Meanwhile, a huge amount of financial and environmental resources have been spent on the production of lost or wasted food, amounting to 1.3 billion tonnes annually as of 2012. Food loss and waste show poorly functioning food systems. Represents the waste of resources and emissions (FAO 2012c).

- **Loss of living resources and biodiversity**

Agricultural sustainability depends more on biodiversity conservation which is essential for diverse species preservation. The genetic base of most crops and animals in the world is narrow. By 2004, up to 75% of the genetic diversity of crops had been lost, and additional 15–37% is estimated to be extinct by 2015 (Thomas et al. 2004). Deforestation is a major threat to three-quarters of the world's terrestrial biodiversity habitants.. In the tropical rainforest, deforestation has drastically caused the loss of more than100 species in a single day (World Bank 2004). Up to 22% of the world's 8300 species of animal are endangered, with 8% were already extinct during this period (FAO 2012d). Freshwater ecosystems and wetlands are threatened by excessive water scarcity and pollution. In the ocean, almost 30% of the stock was overfished and 57% was fully utilized (FAO 2012e). In addition, by 2008, a significant proportion of aquatic animals captured each year had been destroyed and deep-sea ecosystems were threatened by trawl nets (FAO 2008).

2.3 The Way Forward

The future of sustainable agriculture faces uncertainty that gives rise to serious questions and concerns regarding its performance and uncertainty. These uncertainty revolves around the following factors:

- State of natural resources
- Technological progress
- Climate change
- Population growth
- Income distribution
- Dietary choices

There is no guarantee of how the above factors will evolve in the long-run; but they are certainly will shape the future. The entire world; academia, international organizations, civil societies are vehemently brainstorming on alternative scenarios that could highlight potential part ways for sustainable agriculture.

There is a need for a change on how the environment and natural resources are managed; “for a better tomorrow without an option”. For agriculture to be sustainable and meet fully the Sustainable Development Goals (SGDs) targets, as envisaged by the 2030 Agenda; GHG emission, resource depleting farming, food loss, and waste must be addressed. To move from where we are to where we want to be, every society will be required to review the assets used to produce goods and services.

As enshrined in the SDGs, international organizations and countries that can reasonably cushion the cost involved in the necessary transformation have to provide support to others that are negatively impacted by unsustainable agriculture; and help them prepare a better future for the next generation. Every country must be committed to the transformation of the process to achieve the future we want—Rio+20 (FAO 2018).

3 Conclusion

Agriculture has been with us for ages. To make agricultural production sustainable entails managing the natural resources in such a manner as to be enough for this generation and the next. The guide to achieving this lies with the principles of sustainability outlined in the text. All the aspects: aquaculture, crop, fisheries, forestry, and livestock should be managed appropriately, to ensure sustainability. Agricultural intensification has adversely impacted the ecosystem, through increased food availability; but does not guarantee future returns. All policies, institutions and agricultural production systems that support global food security should intensify efforts to ensure a sustainable future.

Agriculture depends only on the services of the ecosystem. Therefore, agriculture needs to minimize its negative impact on the environment while optimizing improving natural resources and maintaining efficient use. Sustainable husbandry needs to find a balance between the maintenance of agro-ecosystems and growing demands of society by providing a humane and flexible livelihoods.

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Agriculture-Food Nexus. The Paradox of Sustainable Development in Mexico

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1 Introduction

There is a need to address the overwhelming challenges for the future of agri-food systems (i.e., population growth and urbanization, hunger, obesity, food waste, climate change), both in developed and developing countries, to ensure transformative changes towards achieving long-term sustainability of societies (Brooks and Place 2019). In the construction of futures, the review of the complexity of agricultural, food and sustainable development agendas has been underlined based on a fundamental question: What needs to be done to reduce food insecurity? Food security consists of a multidimensional, developing, and disputed construction, and includes components such as availability, physical access, economic access (affordability), food consumption and use (Foran et al. 2014). For example, to consider drivers and scenarios of change in food security, the CGIAR Global Futures and Strategic Foresight includes several models, such as: crop and livestock; water; multi-market economics; and climate change. These models define relevant scenarios regarding the agri-food systems' performance and policies to address them (Brooks and Place 2019).

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Increasingly since 2010, there has been more literature on the agriculture-food nexus (IICA 2012), however, there is a need to further explore the link between the two to identify possible synergies and complementarities between the sectors that should guide the establishment of sustainable development options under a coherent, integrated approach of research disciplines, socio-economic, technological, or environmental categories, and thematic and policy dimensions. By understanding resource interconnections, the nexus approach focuses on identifying trade-offs and synergies that help to assess the feasibility of allocating resources to meet all demands and guide the design and development of sustainable policies (Cansino-Loeza et al. 2020); in particular, the water-energy-food nexus (WEF) has become a relevant approach in natural resource management for decision-making towards sustainable development (Hamidov and Helming 2020). Moreover, achievement of Sustainable Development Goal Two will require decision making at national and regional levels to achieve synergies among agriculture, water, energy, and land sectors to address trade-offs brought on by climate change (UN 2021).

By analyzing the access and availability to resources at the country level, indices and indicators have been defined to assess and measure the interaction and sustainability performance of the food, energy, and water (WEF) (Yuan and Lo 2020). For Latin America, the security of the WEF nexus have been evaluated through indicators that measure their availability, accessibility and sustainability, which allow projections of resource demands, production, and consumption for future scenarios (Mahlknecht et al. 2020). It has been referred that optimization models may improve planning and resource management based on policy projections to guarantee sustainable access to resources and basic services for the most vulnerable sectors (Cansino-Loeza et al. 2020).

Despite the extensive conceptualization and use of mathematical models to evaluate linkages and trade-offs in the WEF nexus, across temporal and spatial scales, there are missing nexus applications in policies and decision-making, especially when considering regional and local dynamics (Terrapon-Pfaff et al. 2018; Liu et al. 2019). The main constraint consist of the complex nature of “nexus” systems when combined with models of complex interconnections (Dargin et al. 2019). In this sense, efforts to better understand the interdependencies of resources should continue, especially since agriculture-food nexus studies have directed attention to the structural problems affecting food security. This is especially true in Latin America, where the impact of various crises, most recently Covid-19, affect nations differentially based on whether they are net food importers or exporters, their economic development level, and the degree of integration of agri-food sectors into the world market. One means of overcoming these disconnects and working towards sustainability is through a nexus approach using participatory system dynamics models (González-Rosell et al. 2020).

In Latin America it is estimated that the food security problem is not directly associated with the availability of food, given that the region produces enough food to supply its population and still to export. On the contrary, the region has a relevant role to play in securing the world’s food supply with to its broad base of natural resources (land, forests, water, and biodiversity), human resources, and knowledge

(IICA 2012). However, there is a significant impediment in each Latin American country to match the agriculture-food nexus approach with the changing trends of the regional agri-food systems that contribute to converting the conceptual and methodological frameworks into real results throughout the national food production processes. Similarly, despite the increase in studies of traditional agricultural systems and agroecological practices over the past 35 years, which show that their adoption in agricultural systems around the world may be useful to contribute in increasing food production and food security, there are weak links between agroecological knowledge and farmers' practices (González-Chang et al. 2020).

As part of international agendas on food production, family farming has been emphasized as a key to achieving positive change in the global food systems (FAO–IFAD 2019). Latin America has been one of the pioneer regions in placing family farming at the core of its food security and rural development policies, fundamental to promote sustainable development and eliminate hunger, obesity, and all forms of malnutrition. There are 16.5 million family farms in Latin America, eight out of ten farms are in Mexico, which accounts for 5.8% of these (FAO–IFAD 2019). In some Latin American countries, family farmers produce up to 70% of the food that makes up the food staples, besides being the principal source of rural and agricultural employment (FAO 2016).

In the last 30 years, food production in Mexico has undergone significant changes, mainly the reorientation of agricultural policy towards strengthening fruit and vegetable exports and importing basic consumer products such as corn, oilseeds, wheat, rice, milk, and chicken. This policy has divided the agri-food chain into two: one related to international and /or high-income consumers, and another to national markets. At the same time, traditional agroecosystems, practically all of them in peasant families, have been strategic in the survival of families, in some cases providing 55% of their food, but their contribution to food supply remains unclear (Hernández et al. 2017). On the other hand, the Mexican diet has seen increases in the consumption of animal protein and vegetable oils and a reduction in consumption of beans and cereals. From 1988 to 2012, the combined prevalence of overweight and obese adults grew to seven out of 10. In children under five, rates of being overweight or obese jumped from 16.6 to 33.6% (Rivera et al. 2012). From 2017 to 2019 in Mexico the average percentages of malnutrition and sever food insecurity were 7.1 and 11.5, respectively, in the total population (FAOSTAT 2021).

Within this context, there is an urgent need to review the hunger and food access problems in Mexico from the full implementation of the best fit agriculture-food nexus´ perspective. In this chapter, we suggest that the critical interdependence among sustainable agriculture and food security issues in Mexico should be addressed primarily from a regional approach. We assert that the successful agriculture-food nexus should be based on the degree and level of sustainability of Mexico's traditional agricultural systems that develop at regional scales. From the perspective of the environmental, economic and social connections between local and regional agriculture-food systems, beginning with a review of the current data on the status, drivers, and trends of change of Mexican regional agri-food systems, particularly traditional-family agroecosystems, which are recorded and reported by official sources. By illustrating two trends of change for the Mexican case—dietary patterns and validity of traditional agroecosystems—the main aim of this text is to propose regional food production systems as the axis of a new policy of agricultural production, nutritional care, and agri-food research. In discussing these factors, this chapter highlights the importance of the food-agriculture nexus as one of the main components of sustainable development in Mexico. Finally, guidelines on future research needs are presented.

2 Methods and Approach

As part of an inductive investigation about the status of regional food production systems in Mexico, particularly the traditional ones, our analysis was based on a qualitative approach to review information, data and profiles reported by three official government sources at the federal level: the Ministry of Agriculture and Rural Development (SADER); the Ministry of Environment and Natural Resources (SEMARNAT); and the Agrifood and Fisheries Information Service (SIACON). Unlike using a search string as occurs in databases, we apply the following search terms for documents, reports and texts: agricultural systems; agri-food systems, food systems, sustainable agriculture; food safety; agroecosystems; traditional farming systems; family systems of agricultural production; agricultural regions; and regional food production systems.

Given our exploratory approach of identifying, from a regional approach, the interdependence between sustainable agriculture and food security problems in Mexico, we focused on documents, information, and data that explicitly adopt a regional food production systems perspective rather than focus strictly on the components and sectors of isolated systems or disciplinary domains. For the SADER and SEMARNAT portals, the extension "gob.mx" was applied, which is a domain for the secretaries of State of the Mexican government, both in the "normal or advanced" searches (www.gob.mx/busqueda). In the SIACON portal (https://nube.siap.gob.mx/index.php/s/AQROGZKKqEek6wh), the system was downloaded, and the search proceeded. For both cases, official reports in Spanish were exclusively searched and no journalistic news sources were included, which resulted in a sample of 75 texts, published between 2010 and 2020. The relevance of each text and information was evaluated according to the following criteria: (1) the source explicitly addresses some of the keywords; (2) the material offers systematized data that regionally integrate the issues of sustainable agriculture and food security; and (3) the text and information focuses on the distinctive characteristics of regional food production systems (production and consumption), their results (food security) or dietary patterns. This data was used to test the relationship between that the success of the agriculture-food nexus must be based on the degree and level of sustainability of Mexico's traditional agricultural systems on a regional scale.

However, given the high degree of generalization of the data and information found, as well as the limited usefulness of the few findings and their limitations to identify, characterize and determine the main trends of regional change of the traditional systems of food production in Mexico. A narrative analysis scheme was designed, aided by a literature review, based on three themes: dietary patterns, trends in food production, and proposals for regional food production systems. Based on these issues, relevant research needs were formulated to fill the identified gap of official systematized information on the traditional agricultural systems of Mexico that are developed on a regional scale.

3 Results

3.1 Dietary Patterns

In Mexico, 43.6% of the population (53.4 million people) lives in poverty and an additional 7.6% of the national population (9.4 million people) live in extreme poverty (FAO 2019). Overall, 20.1% of the population, equivalent to 23.4 million people, live in food deprivation, without access to sufficient or quality food (CONEVAL 2017). Thus, within the framework of the global transformation of the current agri-food system that guarantees people's health and societies' sustainability (Chen and Antonelli 2020), it is clear that Mexican initiatives and policies to promote health-enhancing dietary behaviors are compromised by consumers' limited or inconsistent access to affordable and safe fresh food, what is known as the agriculture-nutrition-income nexus (Underhill et al. 2020). Added to the unhealthy diet context is the difficulty for public health interventions to raise awareness among local and regional populations to achieve a comprehensive and consistent dietary diversity with good food choices and healthy dietary behavior that reduces rates of non-communicable diseases, nutritional deficiencies, and malnutrition.

Before 1990, the main food issue studied in Mexico was malnutrition; however, health and nutrition specialists began to document and warn of the abrupt growth of overweight and obese populations resulting from food consumption patterns determinant of chronic non-communicable diseases. Since the 1980s, diabetes is the leading cause of death in Mexico followed by heart disease. Noticeable health changes are associated with nutritionally deficient food consumption trends such that the lack of food access was 24.7% in rural areas (INEGI 2016). The consumption of nixtamalized corn tortillas and beans (a source of protein and fiber) has drastically decreased in the Mexican diet. National per capita tortilla consumption went from 144.9 kg in 1980 to 78.5 kg in 2008 and was even lower in urban areas at 57 kg (Guzmán and Nuñez 2014). National per capita bean consumption, a source of protein, fiber and folic acid, and a crop that the government reduced support for planting and marketing, went from 18.9 kg in 1990 to 10.8 kg in 2010 (Rodríguez 2018).

Due to the high concentrations of the urban population in Latin America, sales of ultra-processed products commonly available are linked with high obesity rates (OPS 2015). In 2013, the sale of ultra-processed food in Mexico, which ranked first in this region, was estimated at 214 kg per capita. Comparatively, Mexico had slightly lower consumption than Germany (218 kg) and Canada (230 kg) while the highest per capita consumption of ultra-processed food and beverages occurred in the United States (307 kg) (OPS 2015). Among the factors that influence supply and demand of processed foods in the Global South are urbanization, rising incomes, changes in the retail sector, trade policies, and market deregulation. These factors have implications—consider that in 2013, 63% of soft drinks in Latin America were marketed by a US company (OPS 2015). In 2012 in Mexico, average per capita soft drink consumption was 163 L, while in the United States it was 113 L (García 2012).

Another critical aspect of agri-food systems is the food waste that occurs during distribution and consumption. In the face of global famine trends, unfair food distribution, loss of the social value of food in certain groups of modern society, and social and State neglect permit irrational use and pollution of natural resources and common goods by large producers overproducing for speculative management of the market. It is estimated that close to half of the food classified as waste happens at the end of the production-consumption chain, while 47 million people in Latin America (FAO 2014), 23.4 million of them in Mexico (CONEVAL 2017), have limited access to food or the means to produce their own food.

It is estimated that one-third of the food produced worldwide is wasted each year, equivalent to 1.3 billion tons of food and 936,000 MM, (FAO 2020a). In Latin America, 11.6% of food is lost from production to retail trade, which is equivalent to 220 million tons per year with an economic cost of 150,000 million dollars (FAO 2020a). This amount could meet the nutritional needs of more than 47 million people in this region; that is, 7.4% of the region's inhabitants. (FAO 2020a). In Mexico, it is estimated that about 37.3% of food production is wasted each year, in a calculation based on 34 products of the basic food basket, such as tortillas, rice, tuna and egg (SEDESOL 2017), 20.4 million tons of food are wasted each year (León et al. 2021). Almost half of what is wasted are fruits and vegetables (46%), cereals (29%) and animal, dairy, meat, and fish products (25%) (SEDESOL 2016). This waste occurs while 23.4 million people struggle to obtain food (CONEVAL 2017). It has been recognized that food losses and waste reduce the food systems' sustainability, reduce local and global food availability, generate income losses for producers, increase prices for consumers, negatively affect their nutrition and health, and contribute to environmental pollution due to the inefficient use of natural resources while undermining food security (Corrado et al. 2019).

3.2 Trends in Food Production

Mexico is expected to maintain a minimal increase in food production in the next decade (FAO 2020b); however, by 2030, an increase of 27.8% in food production is projected, considering consumption trends and population growth, which by 2040 will reach 130 million inhabitants (SAGARPA 2017; SEMARNAT 2021). Similarly, the urban population, which was 80.2% in 2018 (rural population was 19.8%) is expected to grow (FAOSTAT 2021). As part of a Mexican agri-food profile, three agricultural-population zones can be delineated: (a) the north of the country where lands are arid and semi-arid, large-scale irrigation production is present, far from consumption areas, but connected via investment in transportation, distribution and agroindustry; (b) the center of the country, characterized by tropical and temperate climates in the highlands, where small, medium and large producers produce a wide variety of products, from grains, vegetables, fruits and livestock, under both irrigation and rainfed conditions in an area rich in water resources, in greater proximity to consumption areas, and the territory of numerous indigenous communities; and, (c) the center-south, where tropical or temperate climates predominate in isolated, mountainous, rural areas, with limited highway and road infrastructure links to consumption areas, and most production is on a small scale, with less agro-industrial development (FAO 2019).

Mexican agriculture highly depends on the regularity of environmental conditions for production, especially when the socioeconomic and ecological-geographical characteristics of the country are characterized by great sectoral vulnerability (Gonzalez 2017), in particular heavy rainfall, droughts, floods, frost and hail, all of which make smallholder farmers highly vulnerable to variability and climate change. To illustrate the climate variability, consider that between 2010 and 2015, 45% of the national territory suffered two years of droughts (Hernández and Madin 2020), while in 2015 the abundant rains of El Niño severely affected agricultural and livestock production in the south (Gaucin et al. 2018).

Sixty nine percent of agricultural production units use chemical fertilizers, which has significant environmental impacts, with repercussions on waterbodies, fish, birds, and mammals (FCEA 2021). The average annual consumption of pesticides in Mexico during 2009–2014 was 111,504 tons, ranking third in the Americas, behind only the United States and Brazil (WHO-FAO 2018). Likewise, more than half of the territory (53%) suffers some degree of erosion. As a result of agricultural production, in 2010 greenhouse gas emissions from agricultural production were estimated at 91.7 megatons of carbon dioxide equivalent (CO2 eq), which represents 12.3% of the national total, 46.2% of which come from crops (World Bank 2014).

In Mexico, there are several traditional agricultural systems and food production processes with a regional and domestic proximity character, whether merged, promising or avant-garde. These have heterogeneity of sustainability features, such as efficiency in using natural resources, conservation of environmental assets and services, protection and strengthening of rural livelihoods, and local knowledge production, among others. These traditional sustainable systems are highly diversified and distributed throughout the year, which makes their quantification and monitoring difficult, at the same time as the entire official Mexican statistical effort is based on crops and not on production systems. Such is the case of corn, around which the idea of food security and sovereignty in the world revolves (Tanumihardjo et al. 2020), and Mexico, a country that is the center of its domestication and a center of diversity, for which the existing statistical information is registered as an isolated crop and not as maize, which is the predominant system of corn, beans, and squash polyculture. Despite this, it states that commercially oriented farmers (yields above 3 t ha^{-1}) produced enough in 2010 to potentially feed 55.3 million people; and farmers (yields less than or equal to 3 t ha^{-1}) produced a sufficient amount of food to potentially feed an additional 54.7 million people, which may be the entire rural population with farming agriculture (21.1 million people). However, at a disaggregated level, there are significant differences by municipalities, since local production may be not enough to feed the entire rural population, while in others, surpluses would be available to feed more people (Bellon et al. 2018).

The degree and levels of sustainability of Mexico's traditional agricultural systems have been evaluated and recognized in global literature (Putnam et al. 2014). However, there is currently not enough information or statistics to review their status, drivers, and trends of change comprehensively and continuously, based, for example, on models (crops, water economy, and climate change) required for food security (Brooks and Place 2019). The principal sustainable systems related to food production are concentrated in the central and southern regions of the country, coinciding with areas of greater biological and cultural diversity, described below with scalar information and in Table 1.

(1) Polyculture of maize, including native varieties of corn, beans, and squash (*milpa*) for self-consumption and therefore household food security, is of major cultural importance. Milpa provides a wide range of other benefits, such as diverse cuisine and multiple products to take part in local and regional markets to obtain income (TEEB AgriFood Mexico Initiative 2020).

(2) Family gardens or ornamental systems are widely spread in urban and rural populations of Mexico due to their capacity to conserve biodiversity, their resource use efficiency, and food self-sufficiency for families (Castañeda-Guerrero et al. 2020).

Table 1 Main traditional agricultural systems of Mexico

Name	Main crops	Principle scale of influence	Main supply function
Polyculture of maize (*milpa*)	Corn, beans, and squash	Local/Regional	Self-sufficiency
Family gardens or ornamental systems	Fruits and vegetables	Local/Regional	Self-sufficiency
Agroforestry systems	Coffee, cocoa, pineapple, ornamentals, and timber species	National	Market
Wetland systems (*chinampas*)	Corn, ornamentals and vegetables	Local/Regional	Market
Agro-silvopastoral systems	Corn, forage and livestock	Local/Regional/National	Market

Adapted from TEEB AgriFood Mexico Initiative (2020), Castañeda-Guerrero et al. (2020), Rosales et al. (2016), Moreno-Calles et al. (2016), Ebel (2020), Martins et al. (2019)

(3) Agroforestry systems, with structural characteristics and ecological processes similar to natural forests, are highly diverse. The objectives of these systems, with wide latitudinal and altitudinal ranges (i.e., terraces, cactus, and tropical forests), are to maintain the soil, fertility, and humidity under the use of various agricultural technologies through the biocultural management of the interaction between wild and domesticated diversity. Agroforesty systems generate economic and ecotourism services with benefits to rural families and communities in housing, health, and education (Rosales et al. 2016; Moreno-Calles et al. 2016).

(4) Wetland systems (*chinampas*, Globally Important Agricultural Heritage System, GIAHS), are considered the most intensive pre-Hispanic agricultural systems present in Mexico to this day. They are extraordinarily fertile and productive due to their soil type, which allows them to host a great quantity and density of crops, cycle after cycle, without rest, providing continuous harvests with high levels of productivity (Ebel 2020), and;

(5) Agro-silvopastoral systems (trees, shrubs, and grasses), are sustainable alternatives for restoring soil fertility and biodiversity, increasing forage and wood biomass, promoting animal welfare, diversify income, and meeting food security needs associated with environment conservation in agriculture and livestock ecosystems (Martins et al. 2019).

Finally, as a relevant contemporary trend in sustainable development, organic agriculture in Mexico is distinguished in three ways: (1) unorganized independent farmers (e.g., vegetable producers); (2) organized groups of farmers (e.g., coffee growers); and (3) industrial business agriculture (e.g. aromatic herb producers). In Mexico, the National Organic Production Law legally recognizes participatory organic certification. In 2016, with 673,967 ha destined for organic production, Mexico ranked 16th in the world, and it is also the world's leading producer of organic coffee with 281,000 ha, corresponding to 40% of its national production (SIAP 2017).

Regarding food supply problems, Mexico is a very vulnerable country to price volatility due to the high level of food imports. Since 2015, there has been a positive agricultural trade balance, imports are lower than exports, but the trend corresponds to both the increase in volumes sold abroad and the higher market value of exported fruits, vegetables, and alcoholic beverages. From the perspective of agricultural production systems and national supply, the most relevant foods in Mexico are corn, beans, coffee, sugar cane, wheat, and beef (meat and milk). However, basic grain imports such as corn, wheat, and rice continue to grow, as well as soybeans and other oilseeds. Although Mexico is the tenth largest food exporter worldwide, domestic food production does not meet domestic demand for basic products such as yellow corn, rice, oilseeds, and wheat. More than 50% of imports are concentrated in four groups of the total agricultural imports in 2020: cereals are 19%; oil seeds and oleaginous fruits are 13%; meat is 13%; dairy and other animal origin products are 8% (SIAP 2020).

Due to the wide geographic and socioeconomic contrasts between Mexican regions (Gouttefanjat 2020), e.g., scarce undeveloped rural areas in the north and large rural regions with high levels of inequality and poverty in central and southern Mexico, two major problems emerge from the perspective of food distribution and consumption: (1) unequal access to sufficient and quality food among the population—in 2016, 24.6 million Mexicans, 20% of the total population, were food deficient (FAO 2019); and (2) change in diets and food consumption patterns have substituted the consumption of vegetable protein for animal protein in several sectors of the population and increased the consumption of processed foods high in fat and sugar. Over the last 40 years, the share of cereals and beans in the national diet has decreased, while meat, eggs, oils, and fats have increased, reflected in significantly increased import volumes.

3.3 Proposals Regional Food-Production Systems

The interfaces between agriculture and food in Mexico occur within the framework of diverse regional expressions, defined under dynamics of complexity in terms of obstacles and structural, institutional, and informational asymmetries faced by actors integrated into one or more levels or subsystems, such as agriculture, food, and dietary patterns. These regional dynamics are linked to a greater demand for resources, including food, water, and energy, which has serious implications for the design and implementation of strategies that comprehensively guarantee food, water, and energy security for the country's sustainable development. Faced with these challenges, however, it has not yet been rigorously identified in Mexico up to now, the regional profile of the demographic, economic, environmental, and productive changes that produce such complexity.

The greatest paradox for the development of sustainable food production in Mexico is associated with the design of regional strategies to achieve food sovereignty, mainly to reverse the concentration of financial and water resources that are focused on limited areas, on export products (fruits and vegetables), or on cereal and fodder industrial agriculture systems (corn, wheat, soybeans, and sorghum). In this sense, public agricultural development policies should not only redistribute subsidies to marginalized and impoverished farmers in the central and southern regions of the country but also differentiate support programs and projects for each region, according to their biophysical, socioeconomic, and organizational diversity. Thus, the development of planning and operation schemes for agricultural restructuring programs and projects towards sustainability should be based on the characterization and diagnosis of the current state of the agricultural production systems of each region and the types of agricultural producers, as well as the recognition of their main limitations and potential for food production.

In particular, gradual changes in agricultural production regions under an industrial model could imply (a) reduction and more efficient use of fertilizers; (b) progressive elimination of pesticides by modifying cultural practices, increasing biodiversity and biological control with native organisms; (c) reduction of greenhouse gas emissions; and (d) efficient use of irrigation water through technological change and restructuring to crops with lower water demand. For medium-sized producers with trade surpluses, there are two major change trends: (a) the creation of financing schemes to increase their productive capacities under agroecological or even organic management schemes, with regional models of biofertilizer production, biological controllers, and organic fertilizers; and (b) investment in the construction and maintenance of small, highly-efficiency irrigation works.

For subsistence farmers, both ensuring local or micro-regional food self-sufficiency, generating higher value-added products, and creating direct marketing spaces are required. Therefore, several actions must be implemented, including (a) harvesting, storage, and piping of rainwater; (b) rescue and use of agrobiodiversity; (c) progressive elimination of pesticides; (d) efficient use of fertilizers; (e) payment for environmental services in areas with agroforestry and forestry activities; and (f) training and support for the transformation of primary production to healthy and artisanal products. Regarding organic products, which represent a small segment of Mexico's agricultural sector, these have contributed to improving the organized farmers' income with less environmental impact. However, the creation of policies is desirable to improve participatory certification schemes, more accessible prices for all consumers, new direct marketing, and financing networks, as well as the development of monitoring systems to assess the economic, social, and environmental impact of organic agriculture.

While Mexico's wide agrobiodiversity is protected and exploited, it is necessary to recover the national production of seeds for food for local, regional, and national human consumption. Concern is significant enough that a project is currently underway to evaluate the relationship between agrobiodiversity, the commercialization of products derived from it, and food and nutritional security in Mexico (GEF 2021). It is expected that the development of policies and strategies that assess the knowledge of traditional agroecosystems and cultural methods that maintain agrobiodiversity in Mexico will necessarily support the sustainable use, resilience, and conservation of agrobiodiversity itself.

Given that Mexico does not have sufficient capacity in the production of chicken, pork, beef, and milk, it is essential to generate alternatives to regional production and marketing systems, as well as a new food policy to promote healthy change in dietary patterns, under the framework of new food production, distribution, supply and consumption models. For example, the challenges related to cattle meat substitution involve consumer-specific marketing strategies, taxation on meat products, and subsidies for productive alternatives (Jiang et al. 2020). Likewise, the replacement of livestock feed and the transformation of livestock management systems, with greater energy efficiency and lower environmental impact, are options for the establishment of agrosilvopastoral systems and the use of high-protein shrub and tree species that could be disseminated on a larger scale, while assessing efficiency and adaptability for the country's different regional climatic and soil conditions.

The redesign of food production systems under local or micro-regional production and consumption criteria is required. Both agricultural and livestock production sites must be closer to domestic consumption sites and distance from production sites to consumption sites must be reduced. The environmental conditions of each region and the cultural food patterns of the populations must be simultaneously addressed at the same time. In this way, the tendency towards the homogenization of eating habits and patterns, and the enormous energy expenditures in transportation for agricultural products and inputs from distant parts of the country or abroad are reduced.

Ensuring sustainable food production in the different regions of Mexico involves various strategies, such as (a) improve the production units' productivity and efficiency; (b) prioritize and increase the areas cultivated with cereals and legumes that ensure the provision not only of carbohydrates but also of protein and vegetable fats for human consumption; (c) gradually modify consumption habits towards schemes that restore agrobiodiversity and reduce the impact of livestock and agriculture on soils, vegetation, and water resources; and (d) boost incentives, regulations, and appropriate payments for traditional agroecosystem services. In short, we must rethink and invest in the links between multifunctional ecosystems, technologies, food, and regional populations.

4 Future Research Needs

Undoubtedly, understanding the interactions, connectivity, and feedback loops that occur in Mexico's regional food production systems requires change. The planning of processes and dynamics is needed to evaluate agricultural and livestock production activities. Such planning should include food processing, marketing, and consumption, and these should based on assessment of the productive, social, environmental and nutritional impacts and results, and improvement of the population's well-being associated with agriculture and food systems. Similarly, there is a need to develop regionalized food waste and loss reduction management policies and strategies (Hoehn et al. 2020).

In this regard, research, technical monitoring, and comprehensive evaluation of sustainable agricultural food production imply a bigger commitment to key decision-makers in farming communities, agricultural enterprises and local governments for the design and implementation of regional agricultural and food policies that address the challenges and transitions of sustainable development in Mexico. To this end, we can outline two priority actions, namely:

1. Create an agroecosystem database—this could include information on agroecosystems that will allow for a more accurate diagnosis of the inventory of productive and environmental resources. It could also include knowledge and techniques developed, tested and effective for the design of national strategies that provide regional solutions to the major food production and consumption issues. For example, understanding the nature and multidimensional character of the traditional agricultural and agroforestry systems implies not only identifying the application of strategies and technologies to protect soil, water, and agrobiodiversity, promote crop diversification and strengthen the management for access to inputs, services, and techniques required for production, exchange and

marketing; but it is also necessary to identify the food transformation processes, consumption habits and dietary patterns of local populations.

2. Conduct a comprehensive meta-analysis of the information generated by the State secretaries, higher education and research institutions, NGOs, and nonprofit and producers' organizations—this could identify the correlation and status of the agri-food system indicators and performance values, measured in different regions and/or time scales. Generate indicators that contribute both to the work of Mexico's three levels of government (federal, state, and municipal), as well as to the socio-environmental and productive dynamics of producers, distributors, marketers, and consumers. The goal would be to generate a national monitoring, follow-up, and evaluation system of regional agri-food systems, particularly of traditional-family agroecosystems, with analytical-value indicators and interdisciplinary approaches that acknowledge all the problems, trends, and challenges of the food production stages and consumption that help to elucidate more resilient and equitable pathways towards achieving the sustainable development goals.

Given the increase in Mexico's urban population, an adaptive approach would consist of regional (van Doren et al. 2021) or city-region food systems. These units enbrace a complex network of actors, processes and relationships related to agriculture, processing, marketing, and consumption in a particular defined geographic region that includes, regularly, an urban center and its surrounding peri-urban and rural hinterland with flows of people, goods, and agroecosystem services managed in a regional landscape (Blay-Palmer et al. 2018). Particularly, it is necessary to understand how different food subsystems interact, the nature of the system's boundaries, and the multiple ways in which the Mexican agri-food system relates to other regional, social, and environmental systems. More conceptual and applied research is required to comprehensively understand the performance determinants of the agriculture-food nexus in Mexico.

5 Conclusions

Due to wide geographical and socioeconomic contrasts between Mexican regions, different agricultural production systems exist that determine unequal patterns of food distribution and consumption. This causes differentiated access to food quantity and quality in the population as well as change in diets and consumption patterns of foods, in certain times and regions, manifests in relative scarcity of foods that contribute to hunger and malnutrition. Likewise, in other regions this leads to growth in the overweight population with increases in chronic diseases such as diabetes and cardiopathies.

In Mexico, to date, the regional profile of demographic, economic, environmental and productive changes that produce the complexity of unequal food distribution and consumption patterns has not been rigorously and systematically identified. The challenge to improve food security in the face of the challenges of sustainable development, under different scenarios of regional change, implies the urgent need to review the problem of hunger and access to food. The greatest paradox for the development of sustainable food production in Mexico is associated with the design of regional strategies to achieve food sovereignty, based on biophysical, socioeconomic and organizational diversity. In this way, the agricultural reconversion or redesign of agricultural production systems towards sustainability should be based on the characterization and diagnosis of the current state of agricultural production systems and the types of agricultural producers in each region, as well as the recognition of its main limitations and potential for food production. It is estimated that the traditional agricultural systems of Mexico conserve a different environmental and geographical logic that is focused on the achievement of local and regional food self-sufficiency.

There are several beneficial traits of agroecosystems, which include the conservation and expansion of various components. Among the benefits of agroecosystems are: agrobiologically and cultural diversity; polyculture and agroforestry systems; natural resource use efficiency; soil fertility and humidity under the use of various agricultural technologies; diverse gastronomy; multiple products to participate in local and regional markets to obtain income; food self-sufficiency for families; ecotourism services with benefits to the local inhabitants of housing, health and education; and, household food security. Taken together, the above criteria should be considered crucial to policies implemented to improve food security in countries like Mexico that face such challenges.

In this context, it is imperative that research, technical monitoring, and comprehensive evaluation of sustainable agricultural food production be part of a commitment by key decision makers in agricultural communities, agricultural companies, and state and local governments in the design and application of regional agricultural and food policies to address the challenges of sustainable development in Mexico. Two priority actions are required: (1) deepen the knowledge of the specific agroecological conditions of each region of Mexico through the construction of a database with information on agroecosystems; and (2) carry out a process of systematization and a comprehensive meta-analysis of the information generated by the secretariats of State, institutions of higher education and research, NGOs, and civil and producer associations that identify correlations and status of indicators and performance values of the agri-food system, which are measured in different regions and/or time scales.

This text addressed three themes: dietary patterns, trends in food production and proposals for regional food production systems, in order to illustrate the trends of change necessary to face the challenges of sustainable development in Mexico from the perspective of the agriculture-food nexus.

However, the work has restrictions due to the lack of systematization of official information to identify, characterize and determine the contributions to regional food security that traditional food production systems have in Mexico. Although the methodological design involved the review of information, data and profiles of the regional-traditional food production systems reported by three official government sources at the federal level, due to its broad level of generalization, our hypothesis that traditional agricultural production systems are the base for sustainability of the agriculture-food nexus in Mexico, could not be tested. Thus, this chapter is mainly exploratory and narrative, taking into account and integrating the contributions of case studies and literature on the subject. Examining the interactions, connectivity, and feedback loops that occur in regional food production systems in Mexico would have provided a much more comprehensive basis for evaluating agricultural and livestock production activities, from processing to marketing to consumption of food. Such an assessment would include the impacts, productive, social, environmental and nutritional results, and improvement of the agricultural population well-being, food systems and the population in general. Likewise, the inclusion of the analysis of determinants and complex dynamics of the obstacles, and structural, institutional, and informational asymmetries faced by regional actors in one or more levels or subsystems, such as agriculture, food, and dietary patterns, would have offered bases for proposing the design of specific multidimensional strategies for sustainable development to improve regional food security in Mexico. In conclusion, we hope the conceptual considerations and criteria we note regarding the agriculture-food nexus point to further research on all levels of the potential of traditional agricultural systems linked to regional production patterns to contribute to food security.

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Prosocial Partnerships – A Scalable Pathway to Sustainable Agricultural Development

Connor F. Harron and Richard A. Matthew

1 Introduction

This chapter highlights stories from an inductive, ethnographic dissertation that explores the social challenges to sustainable food cultivation. Results from the investigation reaffirm findings from Ostrom (1990) and Atkins et al. (2019)[1] and can help guide the development of sustainable agricultural partnerships. Selected excerpts are intended to illustrate how design principles drawn from these works can help groups enhance cooperation and inspire positive change that fosters social and ecological resilience. The chapter concludes by proposing an alternative model for cultivating socially and ecologically sustainable bioregional systems of production and distribution. Before diving into the methods and results, it is necessary to provide some context for the discussion.

Agriculture is a major element of unsustainable human practices contributing to two highly interactive challenges-climate change and nature loss-that pose existential threats to humankind and other species (Ceballos et al. 2020). Despite gains in scientific understanding and technological prowess, the transition to sustainability promised at the 1992 Earth Summit has been slow and erratic, and there is growing concern that if the rate of progress does not increase dramatically in the next decade, we will be spiraling towards 4 or 5 C global warming, which would place humanity in an entirely unfamiliar and largely hostile climate regime (IPCC 2021).

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[1] Ostrom (1990) explores the conditions under which groups can avoid the 'tragedy of the commons' and outlines eight key principles necessary for groups to successfully govern common pool resources. Atkins et al. (2019) applies these principles to develop a universal framework for the development of effective and socially equitable groups.

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The pronounced global patterns described above are a result of a "Perfect Storm" of the totality of unsustainable human behavior (Goodrich and Nizkorodov 2017). Ironically, on many fronts, the path to sustainability is well-known. For example, Jacobson et al. (2017) outlines economically feasible roadmaps for 139 countries to achieve 100% clean and renewable energy by 2050. The main impediments limiting the progress of many nations, the authors note, are social and political barriers to prosocial policies and behaviors.

It is not possible to fully quantify the proportion of global environmental change specific to food production, but it is large (Barnosky et al. 2012). Agriculture is the world's largest producer of greenhouse gas emissions and is responsible for 70% of all freshwater withdrawals (Chen et al. 2018). Additionally, the global cycle of nitrogen and supply of bioavailable phosphorus have been primarily impacted by agricultural development and the expanding use of petrochemical fertilizers and pesticides.

The social effects of contemporary agriculture have also been enormous. For example, whereas most of the benefits of modern agriculture have been received by wealthy people in the global north, the poor, especially in the global south have borne the brunt of negative consequences (Matthew et al. 2017).

The COVID-19 pandemic has provided further evidence of the extent of unequal vulnerability. Agricultural workers in rural and peri-urban areas are often at extreme risk due to cramped working conditions and lack of access to clean water, hand soap, or appropriate protective equipment (Benesh and Hayes 2020). The pandemic has pushed 130 million or more people into poverty, reversing global gains in prosperity as eight out of ten 'new poor' are in middle-income countries (World Bank 2020). As of 2021, more than two billion people globally face uncertain access to sufficient food for a healthy life, the vast majority of whom live in rural communities, are indigenous peoples, and/or are small-scale farmers (Institute for Economics and Peace 2020).

Despite the challenges and disparities that face rural agricultural communities in low and middle-income countries, it is in these places that many of the most innovative and potentially transformative experiments in sustainable food systems are taking place (Litfin 2014). Like startups, however, most attempts at developing alternative food systems have either struggled to produce broad social impacts or collapsed within the early stages of implementation.

Still, many examples exist of communities that have responded to destructive global pressures by combining old and new traditions to craft innovative methods of social relations and agricultural production that are both healthy and sustainable (Ackerman-Leist 2013; Litfin 2014). These groups have benefited from the use of innovative approaches to agriculture and the adoption of specific techniques, such as those inspired by Agroecology,[2] that when carefully practiced, have the potential to regenerate the functional capacity of landscapes while simultaneously providing

[2] Agroecology can be defined as the application of ecological science to the study, design and management of sustainable agroecosystems (Altieri, 2002). As a form of agriculture, these 'agroecosystems' are designed to minimize the need for or usage of high energy inputs, and instead utilize genetic diversity as a key organizing principle in order to achieve beneficial and synergistic biological interactions between agroecosystem components that allow for the regeneration of soil fertility, protect crops and maintain production over time.

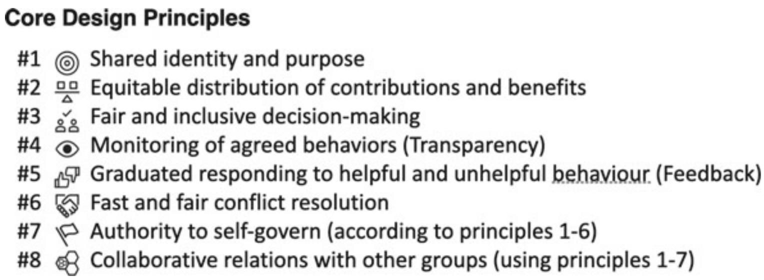

Fig. 1 Prosocial World. (This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License)

abundant sources of food indefinitely with minimal external inputs. None of these technologies though are new, and many of the practices being (re)adopted have ancient roots. The most successful of these groups have demonstrated remarkable resilience even in the face of severe hardship or sudden global shocks, such as when COVID-19 lockdowns swept the world during the first half of 2020.

Groups working to implement sustainable projects and develop alternative forms of social and economic organization need improved guidance that can make the symbolic and often invisible social structures and patterns of human relations more visible and understandable (Atkins et al. 2019). It is in the invisible, social structures that either facilitate or hinder collaboration and teamwork, that achievements being made at small scales can guide and inform the success of initiatives with global transformative potential (Ostrom 2010).

Thanks to Ostrom, there now exists a robust framework for exploring the conditions under which groups can successfully manage common-pool resources and promote long-term cooperation (Ostrom 1990). Ostrom's work focused on the capacity of groups to collectively manage shared natural resources without depleting or overtaxing a system's capacity for regeneration. Atkins et al. (2019) expanded on her theory to develop the Prosocial Framework, which provides practical guidance for applying the eight principles identified by Ostrom to help any group align personal and shared interests, improve effectiveness, and increase capacity to achieve shared goals (see Fig. 1).

2 The Eight Prosocial Core Design Principles

To illustrate how each of the prosocial design principles operates in action, the following section explores partnerships that emerged over two decades within an agricultural community in Costa Rica that has managed to establish itself as a viable alternative to the extractive global food system. The continued resilience of this community, even in the face of a global pandemic, serves as a testament to the important insights to be gleaned from this intriguing experiment. The community in question is far from utopian, yet the progress achieved is still remarkable. Selected stories center on how both their accomplishments and limitations can be traced to the extent to which the partnering organization has, or has not addressed the eight principles first articulated by Ostrom (1990). Understanding how this community has managed to continue working together, despite challenges, holds important lessons for guiding the development of regenerative food systems in the twenty-first century.

3 Methods

The stories highlighted here have been excerpted from the first author's dissertation research (Harron 2020). To investigate the social development of grassroots agrarian movements in Latin America, and identify patterns that can be used to guide future partnerships seeking to promote sustainable agriculture, Harron conducted an interpretive, ethnographic examination into the partnerships that have been developed and maintained since 2001 between a rural agricultural community called Pueblo Arboles in Costa Rica and a foreign nongovernmental organization. This type of inductive research design is intended for theory building, not hypothesis testing, and is appropriate when investigating poorly understood social processes as they relate to specific social phenomena and the exploration of alternative practices (Yin 2003).

Harron spent a total of 18 months conducting fieldwork in Pueblo Arboles over three years between 2017 and 2020, including the completion of over 40 in-depth interviews with organizational and community partners, and an 11-month stint engaged in active participatory observation while serving as an apprentice with the partner organization. To protect the privacy and confidentiality of research participants, the names of all places, organizations, and people mentioned are pseudonyms.

4 Case Selection: Pueblo Arboles, Costa Rica

Observed partnerships that emerged over nearly 20 years of collaboration between the community of Pueblo Arboles and the social enterprise, Centro Sustentable, were successful in many regards. The vast majority were ongoing, the community was vibrant and safe, and there were obvious examples of economic transformation. Numerous local entrepreneurs had been inspired and supported by Centro Sustentable to develop innovative business models rooted in regenerative practices, which in turn were demonstrating themselves to be both economically and ecologically sustainable.

From initial observations, it was clear that the relationships in this community also suffered from many of the same persistent challenges common to partnerships and development initiatives worldwide (Altman 1995). These challenges include economic and gender inequality, alcohol and drug abuse, lack of cultural sensitivity, miscommunication, failures to ensure accountability, and a loss of trust, to name a few examples.

The case of Costa Rica is of particular interest due to its widespread recognition as one of the leading models globally for sustainable development (Díaz and Mascetti 2016). As Ostrom (1990) first proposed, the authority to self-govern (principle seven) and the presence of legitimate forms of good governance are important features of groups that reach their highest potential. By examining one fascinating community within this internationally well-regarded country, Harron sought to simultaneously highlight the ubiquity of some challenges facing humankind as well as explore the potential for positive outcomes and transformative social-ecological change.

5 Centro Sustentable

Matthew Ryan and Monica Torres, the founders of Centro Sustentable, met while serving in the Peace Corps in Uruguay in the early 1990s. A decade later they set out with an enormous amount of ambition and idealism to create a sustainability education center in the rural village of Pueblo Arboles. Since Centro Sustentable started in 2002 it has grown into one of the leading sustainability education centers in Latin America. The organization has won numerous awards and received international recognition for its sustainable systems, education programs, model agroforestry practices, and low-impact lifestyles. From 2009 to 2019 they established a 20+ acre demonstration food forest with over 140 different cultivars of tree crops interplanted with nitrogen-fixing legumes, perennial greens, root crops, and culinary herbs. With few inputs, as of 2020 this 'agroecosystem' was providing the bulk of the calories for 14-year round residents and serving as the classroom for dozens of workshops each year. Less obvious, yet equally important, was the role Centro Sustentable has played in facilitating the success of local entrepreneurs, promoting a vibrant community, and leading a transition away from ecologically destructive practices.

6 Results Principle One: Shared Identity and Purpose

From the very beginning, there were a few key principles that Monica and Matthew embraced as crucial to fostering the type of community they wanted to be a part of. In the Centro Sustentable guest book, the founders summarize some of these principles:

> Monica insisted from the moment that we passed through the Centro's gates that we would provide our guests with scrumptious, wholesome food at almost any cost. Food is the centerpiece of life at Centro Sustentable. It brings us together and sustains us thrice daily…. And as is so often the case during Centro meals, the conversation can be as stimulating as the culinary spread. It's commonly a magical combination.

The use of food as a tool to build relationships and foster a shared sense of identity at Centro Sustentable has not been limited to the confines of their enclave. When Monica and Matthew first moved to Pueblo Arboles in 2001, there was no internet and no telephone access anywhere in the community. All communication at that time passed via word of mouth, so one of Matthew and Monica's first missions was to get to know their neighbors. "We'd go over to everybody's houses, have coffee, eat with them, and chit chat," Monica explained before sharing that through these conversations, they were able to arrange homestay opportunities that provided an important source of income for several families and an enriching cultural immersion for guests. In reflecting on how much had changed since they began, Monica shared that "WhatsApp has just completely eliminated all that. It's gone from the visits to WhatsApp in no time flat."

The first few years that Matthew and Monica lived in Pueblo Arboles flew by in a flurry of activity. In early 2002 they launched a volunteer program for young adults interested in sustainable living to stay and learn in exchange for their labor. In May a growing team of local employees and international volunteers helped complete the first two natural building projects on the farm, a composting toilet, and an earthen oven. They planted a large mixed vegetable garden and began growing fresh greens, tomatoes, peppers, cucumbers, maize, and beans. There was a powerful sensation of youthful idealism that countered uncertainty with an abundance of hope.

Matthew shared that "There was also just a belief that what we were doing was good, was right, was fulfilling. It felt like we had genuinely come upon an idea that we were able to get behind, you know, this idea of bringing people together in a space like the Centro has become. It was really something that we felt was needed and that people wanted."

One former volunteer described that during this time there was a "sense of limitless possibilities." Unfortunately, this near-magical sense of creativity and endless opportunity was being preserved by a fragile sense of shared purpose and intention that was only a misunderstanding or disagreement away from being shattered. What is miraculous about this case is not that social tensions eventually boiled over into serious personnel challenges that threatened the existence of the organization. Rather it is that despite the lack of underlying organizational structure or agreed-upon set of norms, values, and expectations, Centro Sustentable managed to avoid collapse and slowly adapt to the obstacles it faced, reorganizing and growing with the community around them over 20 years and counting.

7 Principle Two: Equitable Distribution of Contributions and Benefits

The establishment of equitable contributions and benefits was one area of serious contention at certain points in Centro Sustentable's past. When a core team first emerged in 2010–2012, a lack of written agreements or a clear understanding of what forms of compensation could be expected contributed to a sense of anxiety and resentment that undermined the ability and motivation of the group to continue. One core team member, Sarah James, reflected from her experience, "It's a lot of things that have been said over the years, like, *this is your home. You will always have a home here.* But in wanting some sort of actual legal right to that, to realize that all of that is still based on when things are good… it makes you realize, *this might be my home, but I don't own any of it.*"

While Centro struggled to formalize benefits for their foreign team members, the compensation offered to local employees was more clear, and in some ways offered transformative opportunities to women in the community. For example, in 2008 Monica and Matthew gave birth to their first child, Isabel. While Monica was recovering she was desperate for help in the office. At the time, Lily Garcia was completing a four-month internship in business administration at Centro Sustentable as part of earning her degree in Tourism. Matthew and Monica were so impressed with Lily's performance that they offered her a full-time position as their administrative assistant. After starting her new role at Centro Sustentable in early 2009, Lily spent the next few years working directly with Monica and helped in nearly every aspect of the business.

In reflecting on the relationships between the community and Centro Sustentable, Lily highlighted how "They were not foreigners who arrived with a lot of money and acted like they owned the town as has happened in other cases around the country. Upon arriving, as foreigners they stayed on the same level as the people of Pueblo Arboles." Lily continued that this approach "made people feel calm, feel supported… I mean, I've never seen anyone do anything with more examples of freedom than has the Centro. They have no locked doors, everything is open, everything is there, and maybe about three or four cases [of theft] have happened in 15 or 20 years and it has mainly been people not from here." After a brief pause, she asked rhetorically, "What better example is there than that?".

In continuing her reflection on the impact of Centro Sustentable on the community of Pueblo Arboles, Lily shared that before the Centro opened its doors, it would not have been possible for women like her cousin Brenda to be independent and raise children on their own. "Before, most people had jobs in the field… there were no options for a woman to earn an income, there was nothing before the Centro. Women were in their homes, maybe helping their husbands, but that changed after 2000 when the Centro arrived and said okay, we need women in the kitchen and help with cleaning." Lily explained that although there was not enough work at Centro Sustentable for everyone, quickly other organizations started emerging who were able to hire women for cooking and cleaning work while others launched their own businesses, such as selling eggs and cheese locally to the new ecolodges. Lily explained that as a result of being able to earn wages, "women feel more independent.… Women now feel that *because I have a child I am earning my money so I don't need to depend on the father or my family.*"

The individuals within the community that self-reported having the most success have partnered with family members and friends to launch micro-enterprises and develop value-added agricultural products (e.g. butter, cheese, coffee, chocolate, etc.) to generate revenue through primarily local sales. Because the largest purchaser of produce in the community (Centro Sustentable) values organic practices and is willing to pay a premium price for sustainably produced, local foods, farmers in the community have been incentivized to adopt more regenerative practices and reduce their focus on monocultures, since if everyone was producing the same thing (e.g. corn) they would rapidly reach a surplus that local organizations would be unable to absorb.

This informally emerging circular economic model appears to encourage farmers to diversify crops and coordinate with their neighbors to avoid unnecessary competition. To illustrate this change, Carlos Diaz, a local entrepreneur who successfully converted his family's cacao farm into an award-winning bean to bar chocolate business, explained that in the past if farmers had a good harvest "then people came to us with big trucks. They bought the pigs, the cows, the bananas and cassava, whatever the farmer had to sell and they took it to a large market like in San Jose. Now there is more flow locally… We buy sugar from San Martin, go to Centro Sustentable for ferments, to Finca Chocolate for chocolate, and then we go buy eggs from one neighbor and cheese from another. Now we keep more money circulating within the town, so wealth is definitely growing."

8 Principle Three: Inclusive Decision Making

For groups to succeed in the long run, members need opportunities to make inclusive contributions to group agreements and expectations. Early in the Centro's history, the organization embraced a form of radical equality in their approach to decision making that provided every member of the organization, whether a part owner or a two-week volunteer, an equal say in all community decisions. They wanted to eliminate hierarchy from their societal structure. Over time this situation became untenable because it failed to acknowledge existing power structures that persevered despite the stated position that everyone was equal.

The following section includes an illustrative example which highlights the importance of addressing both principles three and four. As will be seen, eventually, a lack of clarity regarding the distribution of power and authority within the organization appears to have led to a breakdown in trust and lack of confidence in the organization for several team members. As the core team slowly evolved though and they developed concrete agreements for sharing and distributing authority, the remaining team members expressed developing a stronger sense of contribution both towards the overall group decision-making processes as well as personal autonomy over the areas they directly managed. This shift reflects an important recognition by owners and team members alike regarding existing power dynamics as related to ownership, while committing the organization to a path that embraces democratic processes.

9 Principle Four: Monitoring Agreed Behaviors

Although the idea of writing down agreements may seem obvious, it's a surprisingly pervasive challenge observed in the literature on collaboration and teamwork (Bennet et al. 2018). As will be seen with the case of Centro Sustentable, teams that do not articulate collaboration plans are likely to encounter greater challenges to their productivity, durability, and continuity.

Holly Anders first arrived with her partner Sam in 2008. Holly shared that after completing a four-month internship at the Centro they decided to come back to volunteer again in 2009. "During that internship, Matthew and Monica, the owners, approached Sam and me about partnering with them as co-directors in the business. And so from there, they wanted a commitment to work five full seasons in a management role as part of their work-trade agreements for co-ownership and a profit share within the business. And so we did that for five years and then continued for several years after that."

In reflecting on the partnership, Holly made it clear that when those discussions began the Centro was still not recording decisions or making written contracts. "It was all verbal. We made a verbal agreement. And then as the years passed we continued working at the Centro and did a lot of program development and made management decisions and strategic planning and you know, we definitely had a directorship role… We did not have that profit share for the first five years or legal co-ownership."

Holly was finishing her third year working under a verbal agreement as "co-director" in the business with the hope of securing legal co-ownership and profit sharing once the organization was profitable. Despite the lack of legal co-ownership, at the time Holly had complete faith in her fellow team members. Her faith was shaken, however, due to an unwanted sexual advance by Matthew, which added a layer of tension to an already fraught situation.

> That situation created a lot of professional and personal problems for me because after that point I was very upset and I didn't know if I should say something because I felt like if I said something that it would end our community and our business… So I didn't say anything and it kind of isolated me, I think emotionally because I've had this big trust issue, which wasn't just about that situation. It was a realization that this person might not be working in my best interest overall, and I had just made this huge commitment to someone who had all this power over me and who very well might be abusing that power.

To preserve the life she and Sam had carved out for themselves in Costa Rica, she suffered in silence and delayed seeking help, guidance, or counseling for years. Instead, Holly focused all of her energies on developing formal decision-making structures, pushing for legally binding agreements and contracts, and promoting more open forms of communication at the Centro.

In the following two years, Holly succeeded at pushing to create more formal structures at Centro Sustentable for making group decisions. This included developments within the core team to share power and responsibility, introducing the practice of nonviolent communication,[3] and instituting a weekly community check-in meeting to create space for openly discussing and resolving interpersonal disputes. By 2016, the core team embraced an approach that utilized a combination of individual management over areas of expertise and practicing group consent rather than majority voting. These changes reflect important steps in the organizations development to promote more inclusive decision making strategies, acknowledge existing disparities with regards to power and authority, and create formal agreements that helped to ground disputes within a shared understanding of expectations and benefits, as well as consequences associated with unhelpful behaviors.

Navigating transitions like these in teams can be challenging under the best of circumstances. The added burden of coping with the growing mistrust between certain members and lack of personal accountability regarding harmful behavior compounded these normal growing pains into something much more serious. The team's inability to resolve the situation in the immediate aftermath eventually caused three of Centro Sustentable's core team members to quit their posts within the following two years.

10 Principle Five: Graduated Responding to Helpful and Unhelpful Behavior

To better understand how Centro Sustentable has dealt with the issues that have arisen over the years, we again hear from Lily. After being asked if she had ever had any issues with other employees at the Centro, she replied "Javier yes, a lot of times… I don't even know why he is still there…" She trailed off before continuing "There are a few instances that I remember. For example, there was a group here and they came to the bar to go drinking. Then later, when they had already left to go to their rooms, Javier thought the party wasn't over. So he followed them and tried to get with a girl in their place. That happened once or twice." Lily elaborated "I don't know what he was trying to do but once Matthew had to go and tell Javier to *get out of there!"*.

With that summary, Lily then contrasted Javier's case with a former employee who worked at Centro Sustentable in the early years. "He was very disrespectful with the girls and he didn't change. They spoke with him many times and he did not change and then he was taken out." In this regard, the organization had established that they were willing to terminate an employee for misconduct under some circumstances, but clarity regarding expectations of behavior and which actions were forbidden/punishable was a long time forthcoming. This delay may have contributed to the number and frequency of issues relating to sexual misconduct that has occurred over the years.

[3] Nonviolent Communication (NVC) is an approach to communication based on principles of nonviolence. It's not a technique to end disagreements, but rather is designed to increase empathy and improve quality of life (Rosenberg, 2015).

This example is especially pertinent to economic development in small and rural communities. When there are few options for labor and even fewer bridges to burn, how does an organization create effective methods of accountability and enforcement to prevent abusive and/or destructive behavior? On this topic, Monica Torres shared that "it's extremely difficult to play judge and figure out all these situations." She went on to explain that while having clear policies in place helps, actually enforcing them provides a whole other set of challenges. To illustrate her point, Monica shared, "Say Javier overstepped his bounds. He went to try to fool around with somebody. Okay, so we fire him. Now his whole family is without work and has no source of income. I mean there are huge consequences. This family would totally hate us… And that's something really difficult to determine. There needs to be an investigation that goes and figures it all out."

Through experiences like these, Matthew and Monica realized that dealing with problematic behavior is oftentimes an unavoidable part of collaboration and long-term partnerships. They learned that having simple, written agreements that outline both expectations and repercussions associated with specific types of infractions are necessary to prevent ambiguity or a sense of unfair treatment when following through with disciplinary action. Establishing mechanisms that hold all community members accountable to their commitments provides a further challenge, especially when unequal power dynamics persist.

11 Principle Six: Fast and Fair Conflict Resolution

The examples of sexual misconduct from the previous sections highlight the importance of principle six of the prosocial framework, establishing fast and fair methods of conflict resolution (Atkins et al. 2019). To prevent feelings of injustice or resentment from festering, accusations of serious misconduct need to be taken seriously, thoroughly investigated and dealt with transparently and responsively in a manner that focuses on supporting victims' recovery.

Although Atkins et al. (2019) suggest responses to hurtful behavior should become gradually more severe, what appears most important in this process is that victims are not ignored or left in the dark about what is being done and how the situation is being handled. Swift efforts are needed that address individual's concerns, support healing, and when possible promote reconciliation. To build and preserve trust over time, groups need to establish fair and clear procedures for how to address conflicts in a way that is objective and transparent. Formal policies reduce ambiguity associated with these processes and provide a sense of impartiality and transparency so those impacted feel that at least the process was handled in a fair and just manner. This is a crucial step in preserving the integrity of social groups and preventing personal blowback when making challenging organizational decisions.

12 Principle Seven: Authority to Self-Govern

Every group is embedded in a larger society that can limit its ability to govern its affairs. Evidence from Ostrom (1990) and Atkins et al. (2019) indicate that high-performing groups require an environment that does not excessively interfere with the group's ability to govern their affairs or implement design principles 1–7. According to Transparency International (2020), Costa Rica ranks as one of the least corrupt and most democratic nations in Latin America.

Matthew explained that they had easy and reliable access to government officials who were supportive of community goals and objectives. Individual households in Pueblo Arboles breathe clean air and enjoy reliable access to public utilities such as affordable electricity and safe drinking water. In an assessment of ecosystem services in Costa Rica, Berbes-Blazquez et al. (2017) found that having equitable access to these types of ecosystem and public services plays a crucial role in determining human well-being. The individuals and organizations working in Pueblo Arboles benefit from these resources while national pride in conservation helps foster a sense of shared purpose and identity that greases the wheels of trust and collaboration.

13 Principle Eight: Collaborative Relations with Other Groups

To reliably build systems of cooperation, groups need to develop external partnerships, ideally through the application of all eight prosocial core design principles. Although Centro has developed successful partnerships with groups and visitors around the world, it is of pressing interest to better understand how the combination of ongoing global stressors and internal conflicts may impact the continued resilience and viability of organizations like Centro Sustentable. How well equipped are they to weather the storm of a global pandemic given the collapse of international travel and their traditional economic partnerships?

The first author had a chance to speak with Matthew in late 2020 and receive an update on how the COVID-19 pandemic was impacting life in the rural village of Pueblo Arboles. As with many places, the global shutdown eliminated several forms of employment in Pueblo Arboles. Centro Sustentable was forced to lay off most of their full-time employees since their primary source of revenue evaporated overnight. Fortunately, Mathew reported that not all of the impacts from the pandemic have been so burdensome and at least in part, appear to highlight some of the very advantages and appeal these alternative forms of social organization entail. In Matthew's words, when the pandemic hit:

"Well, obviously our business came to a screeching halt, but there are lots of silver linings for us. It's the first time in years we have had time to spend on personal projects and step out of the role we had been in for close to 20 years… It has also been the first big test of the systems we have been able to put in place and how resilient they are. In part, it's why we've been doing this. I've been expecting this at some point in my life to come down the pipeline, and here we are. It's the first big test and you know, it's exciting on that level… It's somewhat validating knowing we are eating increasing calories off the farm and we've entirely eliminated our use of propane. It's just given us this unique opportunity to see that with 14 people we can actually live quite simply and live almost entirely off of the farm and that we can continue to maintain our relationships in the community with regards to supporting the agricultural producers that we can, but it's also been nice to be put to the test… We are [still] able to have community. You know, we don't have to practice social distancing so we are really fortunate. We get to play volleyball whenever we want and we don't have to wear masks. We have a social network that's built into the infrastructure here that allows us to lean on one another."

When asked how the laid-off employees and the greater community were faring, Matthew clarified that all of the staff who lost their jobs received sizable severance packages through Costa Rica's unemployment insurance program, equivalent to 6–12 months of salary. He said additional government programs should mean that most families will be able to maintain financial stability through at least 2021. One of the most gratifying experiences Matthew shared "has been seeing the ways the community has come together to support one another. At least until now, the community has demonstrated a lot of resiliency… I have observed people really reaching out and caring for one another… More food is being planted here now than in the past 10 years, everyone is saying that it's more important now than ever to plant beans and cassava. It seems to me there is a good deal of food security and a social network that at least for now seems to be functioning."

These reflections illustrate that although much of the economic activity in Pueblo Arboles depended upon foreign visitors, the agricultural systems and robust social networks established within the community, as well as the financial support provided by the Costa Rican federal government, provided a substantial degree of resilience. As Matthew summarized, "I don't know what it will look like in two or five years but we are in such a good spot now and have so many creative minds that we will be able to maintain some trickle of money coming in. I don't feel any urgency right now." This calm and confident projection in the face of so much global uncertainty is a testament to the resilient, self-sustaining systems that Centro Sustentable built over two decades.

14 Discussion

The lessons observable in this case demonstrate how by incorporating the prosocial design principles into the establishment of support organizations, partners can more reliably facilitate effective cooperation, foster improved agricultural practices and community-level resilience. In this way projects intended to support sustainable agricultural development can successfully emerge in regions worldwide that help blend local ecological awareness into the development of a society that is more fair and inclusive. Although the scope of individual projects may be small, the combined impact of these types of institutions could be substantial.

The findings here are aligned with a proposal being championed by Brewer (2021), who argues that given the relative inaction by transnational institutions in the fight against global climate change, our best chance to preserve sufficient ecosystem functioning and biological diversity on Earth and avoid worst-case-scenario projections is through the development of a globalized network of bioregional education centers, similar to Centro Sustentable in Costa Rica. This fascinating proposal suggests that by focusing efforts within functional bioregions, organizations can scale efforts to a level that is manageable while having the potential of supporting whole ecosystem well-being. By then collaborating, aligning objectives with other groups around the world, and scaling efforts horizontally, Brewer (2021) argues that the transformative potential is immense.

15 Proposed Model for Co-operative Sustainable Agricultural Development

By drawing from the lessons observed in the described case study and integrating them with the prosocial design principles outlined by Ostrom (1990) and Atkins et al. (2019), the authors have developed a framework for designing Prosocial Co-operatives that can help groups implementing sustainable agriculture projects lay the foundations for long term collaboration and expand impacts to support whole ecosystem wellbeing (see Table 1). A Cooperative structure that is jointly owned and run by its members sharing profits and benefits is perhaps the ideal legal structure to facilitate prosocial outcomes since the principles of shared ownership and collective management directly align with the model of polycentric governance described by Atkins et al. (2019). The following model can guide project framing and development with goals that include protecting farm and forestland from development, improving livelihoods, and/or making sustainable food production viable, affordable, and accessible.

16 The Prosocial Co-operative Design Framework

Exactly how these co-operative design principles operate will depend on the careful assessment of contextual challenges, opportunities, and resources. The appropriate applications of the principles described above are, like the science of agroecology, a highly knowledge-intensive practice that is rooted in techniques developed through local understanding and experimentation (Altieri and Nicholls 2017). By focusing

Table 1 Compiled by the authors, adapted from Atkins et al. (2019)

Prosocial co-operative design framework
1. Cultivate Shared Identity and Purpose: Through food, groups can reinforce and focus on the values they share while forging strong social bonds that are rooted to place. Groups can preserve and reinforce community culture through shared meals, food planting, harvesting, preservation, and preparation rituals, as well as through collaboration on community projects (e.g. litter cleanups, school maintenance, fundraising for students or community members in need of support).
2. Establish Equitable Distribution of Contributions and Benefits: For co-op members, this means establishing equitable opportunities, the benefits of which will be shared by those with initiative and creativity. Co-operative staff and employees need adequate compensation commensurate to time dedicated and skills. By providing centralized community services (e.g. food processing), prioritizing the sourcing of locally produced goods, and reducing transaction costs between members, co-operatives can incentivize agricultural transitions away from extractive monocultural practices and towards the establishment of diversified practices such as agroecology. Additionally, co-operatives can provide value-added and wholesome foods to members conveniently and at affordable prices, while creating opportunities for localized, small-scale, value-added production.
3. Ensure Inclusive Decision Making: To facilitate co-ownership over the project and community outcomes, all members need to have some capacity to contribute to decision making, and the overall guidance of the project should be a collective, representative process. It's thus crucial that groups implement an inclusive, culturally appropriate decision-making process that distributes the burden of leadership. To distribute power within the group equitably and promote polycentric governance, it's important to disentangle decision-making power from fiscal investments, which are typically highly skewed.
4. Monitor Agreed Behaviors: To prevent corruption and discourage misbehavior, peer-to-peer monitoring through normal group interactions are best suited to promote accountability in a non-coercive manner. Effective teams and partnerships typically work out a detailed collaboration plan (above and beyond the specifics of their research or community change plans) during the initial stages of their collaborative projects. Groups that draft living documents and contracts that articulate agreements and outline individual and group expectations benefit from having concrete expectations to refer back to in the case of disagreements while allowing for the potential that agreements may evolve as membership and the context within which the co-operative operates changes.
5. Develop Graduated Responding to helpful and unhelpful behavior: Effective groups have in place responses to helpful behavior (e.g. expression of gratitude, celebrations) and unhelpful behaviors that are intentionally progressive. When members engage in misconduct (i.e. fail to meet mutually agreed upon expectations), co-operatives need a plan to guide moderated responses that progress from overly compassionate (seeking to understand, providing clear requests and warnings), to in extreme cases, exclusion from the group.
6. Facilitate Fast and Fair Conflict Resolution: Repairing the harm caused by misconduct moves the focus beyond punishment to promote healing and healthy re-engagement between group members. By establishing protocols that quickly respond when conflict inevitably arises to facilitate resolution, groups can prevent unavoidable sources of tension from turning into disabling challenges. Organizational leadership will benefit from training in nonviolent communication and conflict resolution.

(continued)

Table 1 (continued)

Prosocial co-operative design framework
7. Seek Authority to Self-Govern: To foster improved group performance, it's beneficial to provide an environment that makes it easier for individuals to govern their own affairs and have critical needs addressed such as healthcare, food, and education so that more time can be dedicated to the pursuit of personal development and inspired action. Cooperatively owned and managed communal systems of care (e.g. healthcare, education, cooking) can support self-governance and personal empowerment by cultivating personal accountability and liberty through reciprocal support structures that maximize available time and energy for members to invest in what both inspires them and nourishes the collective.
8. Create Collaborative Relations with Other Groups: No one cooperative, community, or region can produce all the necessary ingredients/products needed to meet the expectations of modern humankind, nor address the interconnected, global challenges of runaway climate change. Establishing forms of collaboration and systems for sharing information between sister co-operatives can serve to build bridges both within and across bioregions and facilitate scaling through the establishment of additional co-operatives and/or learning centers. Partnerships can focus on both the exchange of tangible goods as well as intellectual ones (e.g. cross-cultural exchanges) and host events that facilitate dialogue between farmers, local businesses, and co-operatives alike. By developing mutually beneficial partnerships between sister co-operatives, the capacity of each group can be enhanced.

on what is local and investing in human resource development, prosocial co-operatives can help communities cultivate self-reliance and shorten cycles between food production and consumption.

17 Conclusion

Throughout human history, our relationship with what many modern cultures call "nature" has been largely defined by the way we acquire food. Many living and bygone indigenous cultures have understood the importance of cultivating a custodial relationship with landscapes, first knowing and serving the ecosystem needs, and evolving ways to feed, clothe, and house themselves in the process. These ways of living are in stark contrast with the advancements that humanity has made under the economics of capitalism and industrial agriculture's domination of the landscape. As articulated in the sixth IPCC (2021) assessment report, we are running out of time to change course before cascading impacts lead to irreversible and catastrophic outcomes for humankind.

The design framework for prosocial co-operatives outlined here represents an attempt to outline a pathway that can help our species get back onto an evolutionary track that will allow for humanity's continued vitality. Prosocial co-operatives can guide human groups towards re-inhabitation of the land so that we are again intimately familiar with the function and stewardship of our local ecosystems. They attempt to restore the losses and isolation that have occurred in our pursuit of economic growth and rediscover the power of living in connection to cooperative groups. They are designed to foster the necessary conditions for humans to live fulfilling and meaningful lives, heal landscapes through the development of mutually enriching relationships, and use delicious, nourishing food to foster connection.

A limitation of the proposed theoretical framework is that it relies upon a post hoc, non-experimental research design. There is need for continued research and the implementation of thoughtful community-based investigations into the development of prosocial co-operatives that incorporate experimental and/or quasi-experimental study designs in diverse contexts around the globe.

The lead author was inspired by his experiences in Pueblo Arboles to play a more active role in developing the types of regenerative agricultural systems that are needed to sustain thriving human life on Earth. After finishing data collection for this research, he and his wife purchased a tiny house and moved onto 20 acres of undeveloped farmland in Northwest Washington State in the U.S. There, they are developing a homestead and collaborating with community partners to prototype a prosocial inspired, cooperatively owned community kitchen and learning center that they envision will spiral outward over time and provide a replicable model for cultivating regional level social and ecological resilience.

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Towards Sustainable Agriculture in Serbia: Empirical Insights from a Spatial Planning Perspective

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1 Introduction

Addressing food security issues through the protection of agricultural land is a central goal of the global agenda (Tanrivermis 2003; Verburg et al. 2013), particularly high-quality agricultural land in rural hinterlands (Zróbek-Rózanska and Zielinska-Szczepkowska 2019). The opening sentence of the preamble of the revised World Soil Charter (FAO 2015) stresses that "soils are fundamental to life on Earth but human pressures on soil resources are reaching critical limits". It states further that responsible soil management is one of the crucial factors for sustainable agriculture and to preserve the ecosystem and biodiversity (Ibid.). Directly corresponding to that is the concept of soil security, the principle that connects food security, water security and energy security (McBratney et al. 2014; FAO, ITPS 2015), whereas soil security concerns the maintenance and improvement of the soil resources to produce food, fibre and freshwater, to contribute to energy and climate sustainability, and to maintain the biodiversity and the ecosystem (McBratney et al. 2012 after McBratney et al. 2014).

Therefore, many countries and cities are already enforcing stricter laws to protect high-fertile areas in their rural hinterlands (Zróbek-Rózanska and Zielinska-Szczepkowska 2019). Land use planning directly affects the pressure on land resources, whether by increasing or decreasing such pressure. On the other hand, land use change is a result of the change in environmental, social and cultural conditions globally. In this context, land use change is the consequence of institutional, economic, cultural, technological and natural driving forces, along with the relevant

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actors (Hersperger et al. 2018). Acknowledging that the current trend is unsustainable and that it risks negative side effects, the EU declared an ambitious goal concerning sustainable land use: to stop the process of land take by 2050 ("no net land take") (EC 2011) and introduced soil sealing guidelines (EC 2012), since soil sealing is a form of land degradation which directly depends on land use change. Namely, the obligation to assess the impact of European policies on land use in the EU and globally is contained in the document *Roadmap to a Europe of Efficient Resources* (EC 2011), which obliges all members to consider their own direct and indirect impact on land use by 2020, by trying to prevent construction by 2050 at the expense of agricultural land and other natural areas. In addition, the analyses of the impact of EU policies on land, conducted by the European Environmental Agency, indicate an explicit influence by the Common Agricultural Policy (CAP) on the condition of the land for the period 2014–2020 (EEA 2016).

Previous attempts to establish internationally binding regulations through a systematic approach to identify and combat land degradation have failed (Montanarella 2015). Hence, many European countries consider soils as a local issue that should be preferably governed locally rather than by a central authority (Ibid.). There is also an absence of a common policy framework and there are no EU-level political or legislative drivers for establishing integration towards the agreed objectives regarding soil (Frelih-Larsen et al. 2016).

In accordance with concepts of "land degradation neutrality." (UN 2012) and soil security, it is necessary to keep the quality and quantity of soil/land resources stable or even improved within certain spatial and current conditions, in order to ensure food security. This approach is also supported within the proposal of the new, *EU 8th Environmental Action Program* for the period 2021–2030 (EC 2020).

Of the total 17 Sustainable Development Goals (SDGs) (UN 2015), almost every one contains some reference to sustainable land use, which requires a solution by 2030. The SDGs encourage a substantial increase in food security to achieve zero hunger and promote sustainable agriculture (SDG 2) while preserving life on land and land degradation neutrality (SDG 15), as well as minimizing the conversion of undeveloped into developed land (SGD 11). By 2030, it is expected that these basic principles will be fulfilled: "to end hunger, ensure access for all people, to double agricultural productivity and incomes of small-scale food producers, to ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, to help maintain ecosystems, to strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and to progressively improve land and soil quality" (Ibid.). A recent study (Zhang et al. 2021) demonstrates that a regardful allocation of future cropland expansion, could balance food production and land biodiversity conservation with respect to SDGs. Therefore, it is expected that an 'integrated land use planning framework' could meet agricultural demands by 2030 (Ibid.). A main task is to spatially reconcile these potentially competing and conflicting goals.

Climate change is predicted to increase the price of food and lead to risk of hunger (e.g. FAO, ITPS 2015). Therefore, food security issues should encourage the implementation of climate policies, especially for policies in the domain of the agricultural sector (Liu et al. 2020). Procedures dealing with climate change can also bring about positive impacts to air and water, food security, land use, and energy, which is in correlation with SDGs (Ibid.). Food security is deeply affected by GDP and uncertainties about the part of the population that is at risk of hunger (Ibid.; FAO, ITPS 2015), but better land management, technological improvements in the energy sector, and socioeconomic changes are recognized as positive approaches for food security, by reducing food prices (Ibid.). On the other hand, a recent study (Molotoks et al. 2021) points out that population growth and land use change could have more impact on food security than climate change has.

Nevertheless, Europe is at risk of not meeting the objective of sustainable land management and reaching no net land take by 2050, as well as of failing some of its own and international commitments targeted for 2030, such as land degradational neutrality (EEA 2019).

There is a concensus that “spatial planning influences patterns of land use and land cover” (Couclelis 2005 after Hersperger et al. 2018), while some studies recognize land-use policies and spatial planning as a fundamental driving factor for many different land-use change processes (Ibid.: 32). Land use planning is “sufficiently comprehensive, binding and restrictive” to contribute to a reduction of land take (Colsaet et al. 2018: 349). In the domain of spatial planning and urbanization, land consumption and land take concepts describe the expansion of the built environment at the expense of the natural environment (agricultural land, forests and other) (Ibid.; Salvati 2014), which makes those two concepts broadly equivalent (Marquard et al. 2020). Based on the sustainability concept and other postulates correlated with sustainability, the spatial planning practice attempts to reach a balance between protection and development (Pantić et al. 2019).

Taking all these factors into account, this chapter deals with issues of sustainable agriculture and food security from the aspect of spatial planning. The basic hypotheses are as follows:

- land use change issues are degradation processes and they are a threat to food security,
- land use planning affects land use change, especially agricultural land change,
- the Spatial Plan of the Republic of Serbia (SPRS) addresses agricultural land issues on the strategic-developmental and general regulatory level,
- agricultural land is a national resource of public importance in Serbia. After describing the methodological postulates of the paper, the next parts explain the physical, planning and institutional capacities for agricultural land and sustainable agriculture in Serbia through an analysis of statistical and empirical data. Such analysis and current global trends have helped to shape the new sustainable approaches and insights for agricultural land use planning at the strategic-developmental and general regulatory level, i.e. at the SPRS level. Finally, the authors have provided some recommendations and guidelines to reconcile spatial conflicts in agricultural land use in Serbia.

2 Methods

This research is conducted using quantitative and qualitative research methods, and is comprised of statistical and empirical data analysis, and an analysis of the institutional and regulatory framework. A background analysis and review of the relevant scientific papers provide a perspective on sustainable agriculture in the context of land use planning.

In order to establish an overview of *physical capacities* for sustainable agriculture in Serbia, the authors provide a representation of agricultural land by data analysis at the NUTS 3 level (with 29 entities). This analysis encompases data on basic land cover and statistical data.

Data on the basic land cover are based on satellite images from 2011 that are compliant with the land cover specification according to the INSPIRE Directive. According to the data on the basic land cover, in the Republic of Serbia agricultural land dominates across the total area (about 49%), followed by forest land, artificial areas and bare land, and water land (Fig. 1).

Geospatial data on the basic land cover and statistical data from the Census of Agriculture (CoA) (2012) have been intersected. The starting statistical category from CoA is available land, which encompasses used agricultural land, unused land, forests and other land. The intersection of geospatial data on the basic land cover and statistical data on available agricultural land shows a strong representation of agricultural land in all parts of country. The structure of available land, which is the starting statistical category from the CoA, is explicitly dominated by agricultural (used and unused) land (72.2%), followed by forest (19.1%) and other land with a significantly lower share (8.6%). According to the data from the CoA, the agricultural land in use has a share of about 64.5% of available land, which also gives a picture of agriculture as a high driving factor for environmental impact. The regional distribution of this land indicates a higher representation of this resource in the north with over 76%, while in the southern region these ratios vary in the range of 42–77%, or an average of 55.6%. Out of about 5,346,600.00 ha of available land in the Republic of Serbia, 8% is unused land, which represents 11% of the total agricultural land.

The agricultural land in use in Serbia is predominantly intended for farming. The share of arable land, gardens and backyards decreases from the north to the south and south-east, mainly in favor of meadows and pastures. In accordance with the geophysical characteristics of the area, which have a decisive influence on the quality of land, the total share of agricultural areas, similar to the ratio of intensive agricultural crops to grassland ecosystems, decreases from the northern to the southern and southeastern areas (Fig. 2).

Next, the *planning* and *institutional capacities* for sustainable agriculture in Serbia are reviewed. This review is based on a comparative analysis and critical analysis of the legal framework, and on actual national strategic documents which regulate sustainable land use and planning practice issues. The relevant laws and strategies concerning agriculture and agricultural land were considered. The starting points are the facts

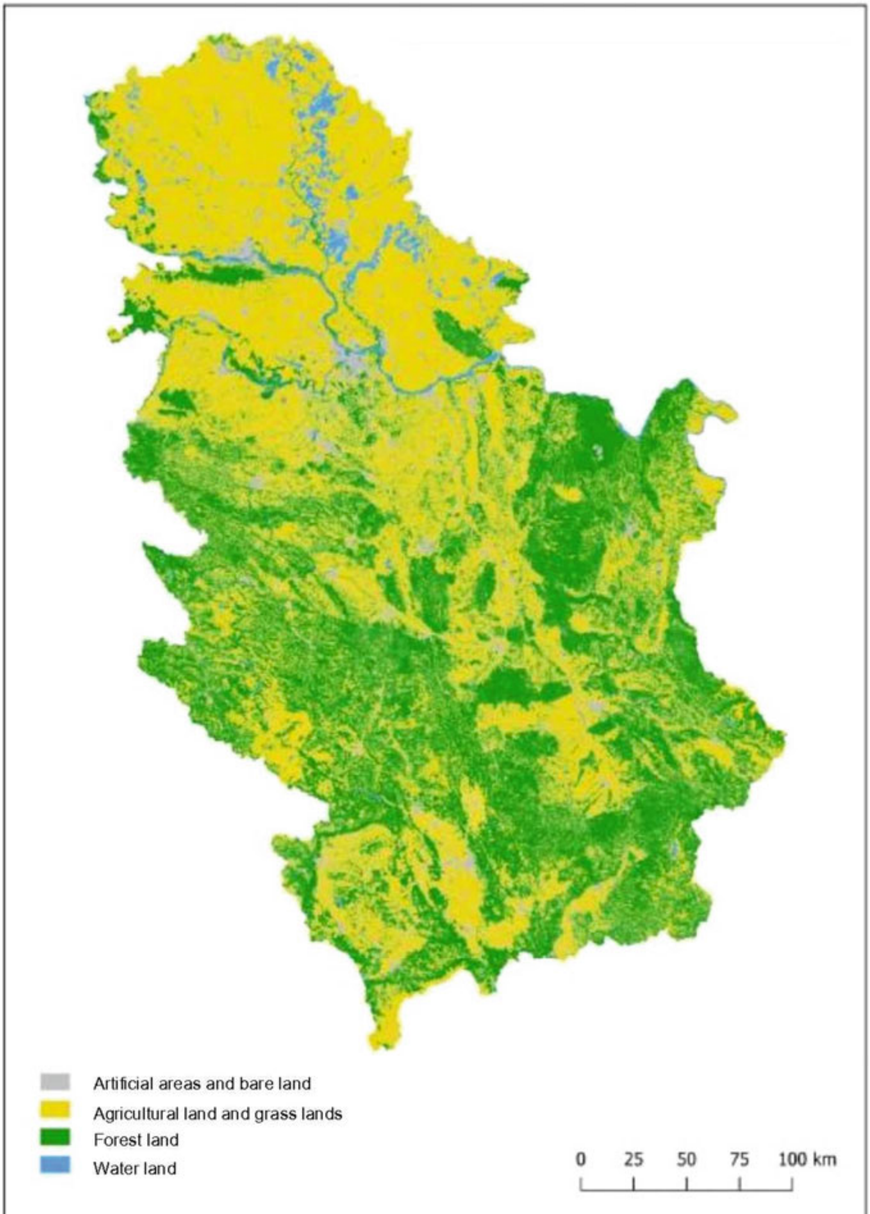

Fig. 1 Basic land cover. *Source* Created by the authors

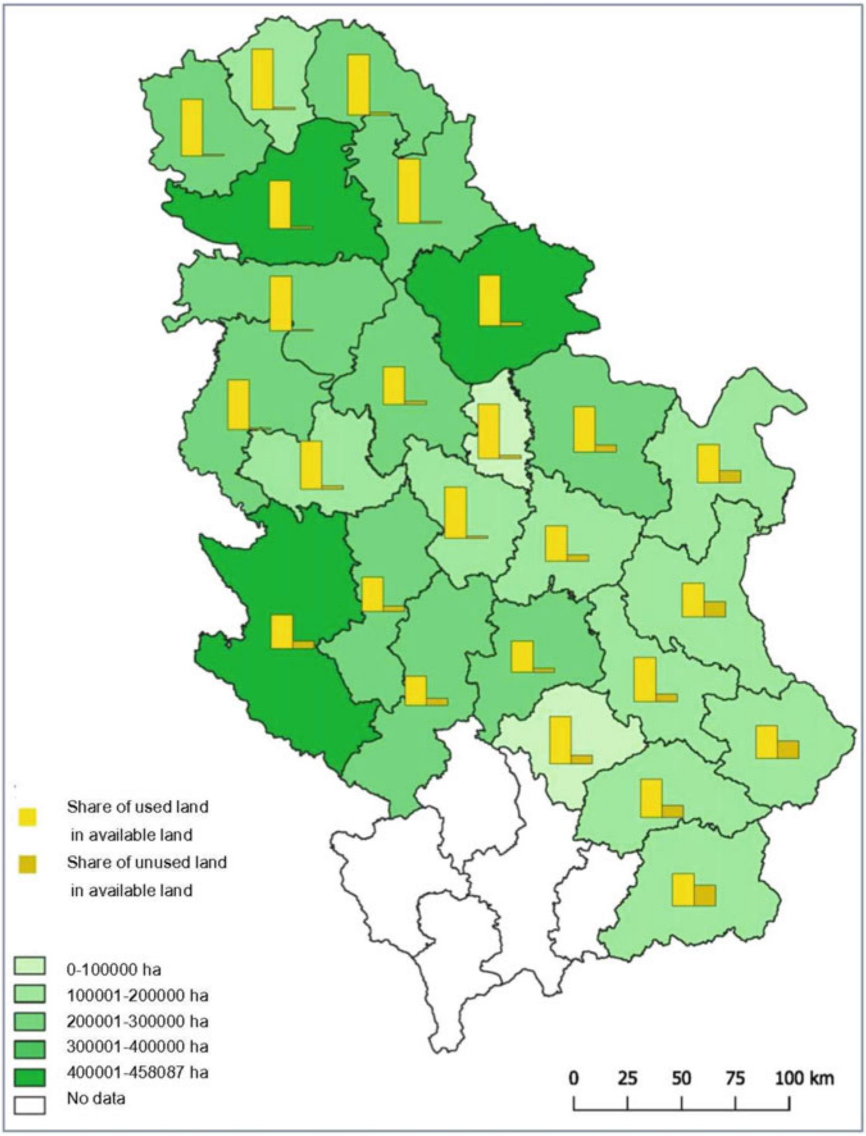

Fig. 2 Available land and agricultural land in use in Serbia at the NUTS 3 level. *Source* Created by the authors

- that agricultural land is "a good of public interest for the Republic of Serbia, which is used for agricultural production and cannot be used for other purposes" (according to the Law on Agricultural Land, Article 1), and

- that in the planning propositions of the Spatial Plans of the Republic Serbia (SPRS) 1996 and 2010–2020, priority is given to the preservation of agricultural land for food production.

In the current time frame, the new SPRS 2021–2035 is being drafted to provide guidelines that propose planning solutions for the next period and that correspond to the current global framework regarding key issues of land use planning, sustainable agriculture and, consequently, food security issues. Such an approach is expected to be useful and encompassed by a new generation of spatial plans at a lower hierarchical level, which will be developed on the basis of the new SPRS in the next period.

3 Results and Discussion

As is the case everywhere in the world, the long-term negative tendency of land use in Serbia is the extensive amount of agricultural land used for construction and the arrangement of settlements, infrastructure, industrial zones, etc., which leads to permanent losses of the productive and ecosystem functions of land due to soil sealing.

Agricultural land, as defined by the *Law on Agricultural Land*, as a *sui generis,* is "a resource of public interest to the Republic of Serbia, which is used for agricultural production" (Law on Agricultural land 2009), so the preservation of agricultural land as a elementary natural resource for food production is a priority in all Serbian strategic documents.

According to the *Law on Environmental Protection*, the sustainable use and protection of natural resources is provided by the *Spatial Plan of the Republic of Serbia* (SPRS) and by the *National Strategy for Sustainable Use of Natural Resources.*

The *SPRS*, as "the primary planning document that sets out a long-term basis for the organization, development, use and protection of space" (according to the *Law on planning and construction*), acknowledges the sustainable use and protection of natural resources since the first SPRS (1996). In the next planning document (2010), the priority objective regarding land is the protection of agricultural land and the conservation of its biodiversity for food production, which is endangered by construction and mining activities.

The National Strategy for Sustainable Development of the Republic of Serbia identified the strategic objectives for sustainable land use. This Strategy recognized changes in land use and land degradation as key indicators of sustainable development related to the use and status of land. Achieving a minimal land occupation is one the main objectives related to sustainable land use. A change in land use is one of the basic indicators of the *National List of Environmental Indicators*, as in the EU, where land use change is monitored as one of the 28 agri-environmental indicators. This indicator shows *land cover change*, i.e. trends in the conversion of agricultural and other natural land into constructed and other artificial land, based on the Corine Land Cover database. Based on the data of the Environmental Protection Agency

(Vidojević et al. 2016), by monitoring changes in the land cover of the Corine Land Cover (CLC) class, 11,367 ha of agricultural land in Serbia changed into artificial areas during the of period 1990–2012. At the same time, the largest changes within agricultural areas occurred during 2006–2012, when they were reduced by 4391 ha.

The *Strategy for Agriculture and Rural Development of the Republic of Serbia 2014–2024* encourages the "extensive use of agricultural land, more efficient use of poor-quality land or non-arable agricultural land, and the controlled re-appropriation of agricultural land".

The *Law on Agricultural Land* prohibits the use of arable land of the highest quality for non-agricultural purposes, except in cases when public interest is determined (Article 22, 23) (e.g. when an urban plan has such stipulations), with the financial compensation for land use changes. According to this Law, "the owner or user has an obligation to regularly cultivate arable land and to use pastures in a sustainable way, respecting the code of good agricultural practice" (Article 59). The *Law on Agricultural Land* excludes the use of arable land under the cadastral class I–V for non-agricultural purposes, excepting in cases of proclaimed public interest. In case of *private agricultural land*, the owner or user of agricultural land has to cultivate arable land in an orderly way and to conduct appropriate agricultural measures. Private arable land that is "not cultivated in the preceding vegetation period may be leased to the competent Ministry for a period of up to three years, with payment of rent to the land owner" (Article 59). The main objective for *public agricultural land* is sustainable land use, increasing farm holdings and the enlargement of the parcels. Public agricultural land is managed by the ministry for agriculture and cannot be sold. Still, it can be used in procedures such as: the lease for a period of 1–40 years; making it available for use at no charge; and the transfer of ownership rights between public agencies, organizations and public enterprises (Articles 60–62).

The *Law on Incentives in Agriculture and Rural Development* ensures agri-environmental measures for support, but obligates the beneficiary of the incentive to respect the standards for environment protection, public health, animal and plant health, and agricultural land welfare.

The *Law on Planning and Construction* envisages construction on public agricultural land, i.e. the formation of a construction plot, only in special cases with the previously obtained consent of the ministry responsible for agricultural affairs. Also, this law prescribes the procedure in cases when the planning document converts agricultural land into construction land, while until the planned purpose is brought about, that land can be used for agricultural production.

Based on the adopted planning act, acquisition of private agricultural land is possible when the public interest is determined. The *Law on expropriation* provides for the expropriation of real estate/land if it is necessary for the construction of facilities for infrastructure, suprastructure, the exploitation of mineral resources, environmental protection and other public purposes defined in the planning act. Compensation for expropriated agricultural land is determined according to the market price of such land, but if that expropriated facility is used for livestock breeding and accommodation or the processing of agricultural products, and that income from these activities is a condition for the existence for land owners, compensation will be another facility in which the farmer will be able to continue performing activities. A special circumstance represents land expropriation in conducting mining activities in densely-populated agricultural areas (cf. Popović et al. 2015).

In cases of a planned change of land use, i.e., those determined by spatial and urban plans, the current legislation in the Republic of Serbia prescribes the procedure through which planning solutions are defined with the approval of the competent ministry for environmental protection for any planned land use changes. Under any change of purpose of agricultural land, such as for urban and industrial purposes, the pressures on land and other elements of the environment increase. Yet, within these planning documents, some examples of good practice of the promotion of urban and peri-urban agriculture can be identified (Manić et al. 2011; Živanović Miljković et al. 2012).

Land use planning in Serbia, as an institutional structure, is "the product of a stable interaction between the set of interrelated rules, procedures and organisational units that allows spatial development outcomes" that care about land resources (Maruna et al. 2019:560). There is a consensus in the local and regional literature that the prevention of land degradation is achieved by spatial planning, and the use of natural resources and goods in accordance with the planning documentation (Belanović Simić 2016; Dorfer et al. 2018). The benefits of preventing degradation and the regeneration of degraded land far outweigh the investments and are reflected, among other things, in increased food security.

Although agricultural land is nominally considered to be one of the most important natural resources, the local level plans in the previous period (2010–2020) reduce it within the balance of its total area, for public purposes (construction of public infrastructure, energy, water facilities, etc.), but also for other purposes that are not public (housing, industry, etc.) (Živanović Miljković and Čolić 2020). The recent quantitative analysis of land use planning and management at the local level has shown tendencies towards long-term reduction of agricultural land (Ibid.)

Agricultural production is highly dependent on the volume and quality of land resources, which are limited and practically unrenewable. For agricultural production, resource management and environmental protection is the basis for ensuring long-term food security and bringing stability and quality to production.

The basis of planning solutions for the area of agricultural land must include the consistency, convergence and compatibility of measures of all policies that directly or indirectly affect the preservation of land and the fertility of agricultural land. The basic problems and challenges regarding agricultural land management relate to the preservation of surface areas and increasing the productivity of agricultural land, so planning solutions or guidelines regarding agricultural land use could be systematized, as in Table 1. At the other hand, this implies strengthening planning-programs, institutional-organizational and normative-legal measures and instruments for the implementation of planning solutions and guidelines given at the level of SPRS (Table 1).

Preventing land degradation is key for ensuring food security. In this regard, appropriate measures should be integrated into the evaluation of land resources when

Table 1 Guidelines and solutions for preserving surface areas and increasing the productivity of agricultural land at the level of SPRS.

Solutions/Guidelines at the level of SPRS	Instruments for implementation
– Development of the Project for identification of contaminated sites and definition/de-limitation of areas where it is necessary to implement soil protection programs (from all types of erosion, reduction of organic matter content, salinization, compaction, loss of biodiversity, conversion of land for non-agricultural purposes, floods and landslides), together with the determination of priority preventive and curative measures, deadlines, competencies, indicators for monitoring the effects and real sources of financing; – Development of land consolidation projects, in order to increase the use of land resources	Planning-programs
– Perform inspection and other supervision of land protection (systematic monitoring of the land quality; and indicators of the risks for degradation, determining the rights, obligations and responsibilities of land owners and users; application of land remediation, remediation and reclamation procedures); – Strengthen the responsibility of local self-government units for integrating land protection and improvement measures into all sectoral policies, implement plans and programs, and other standards and norms regarding land protection measures; – Active and up-to-date exchange of information on agricultural land at all levels of management and competences; – Determination of benefits to private owners for inclusion of degraded and other agricultural lands of lower production and the economic potential in programs for raising multifunctional protective forests, the establishment of forest plantations for the production of biofuels and other non-food raw materials of agricultural origin; – Fiscal burden and penal mechanisms for non-compliance with the legal obligation of regular land cultivation, that are implemented at the level of local self-government; – Afforestation of agricultural lands of low credit value, i.e. lands extremely endangered by erosion and other types of degradation, with special support for the formation of forest plantations for the production of biofuels – Public–private partnership of actors in the implementation of integrated development strategies/programs, at the national, regional and local level;	Institutional-organizational

(continued)

Table 1 (continued)

Solutions/Guidelines at the level of SPRS	Instruments for implementation
– Mutual harmonization of land legislation regarding: (a) updating cadastral data on land—with mechanisms for resolving and ensuring the security of land ownership, inheritance rights, restitution, etc., (b) land markets, including long-term leases; – Amendments to the Law on Agricultural Land with additional provisions that prevent changes in the ownership of state-owned land, and therefore additionally prevent its trade and use for non-agricultural purposes; – Planned direction of the manner of use and preservation of ecosystem and production functions of abandoned/uncultivated agricultural lands, their conversion into forest lands, introduction of restrictive punitive measures and tax policy measures regarding the obligation of regular cultivation;	Normative-legal

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planning land use. This would support the mobilization of effective planning instruments to limit land occupation (Ludlow et al. 2013). In domestic circumstances, such regulations would include the identification of areas with high quality land for production purposes, which must then be included within planning documents (Živanović Miljković and Pantić 2014: 286–287).

4 Conclusions and Recommendations

Serbia stands by an international consensus on the required protection of agricultural land (from permanent land use change and degradation), and its rational use. SPRS directly affects land use on the strategic-developmental and general regulatory level, so every spatial plan at a lower hierarchical level, which will be developed on the basis of the new SPRS 2021–2035 in the next period, will also directly affect land use. Agricultural land is strongly present in all parts of Serbia and agricultural land in use is predominantly intended for farming. So, the long-term priority of land protection and agricultural development, regarding the preservation of areas and the fertility of agricultural land, along with supporting the efficiency of sustainable use of resources in food production and agricultural raw materials must preserve the ecosystem and production-economic functions of land to meet food and other important needs of present and future generations. On that basis, and in accordance with all global strategic approaches in this field, the following principal land use planning solutions on the horizon until 2035 in Serbia have been identified:

- to direct construction areas of settlements and cities to land of marginal importance for agriculture (from the sixth soil potential rating), as well as solutions that encourage the reuse of abandoned sites, and the revitalization and activation of brownfield sites before forming a greenfield site;

- to stop the occupation of agricultural land for economic and socio-cultural needs, except for priority national interests and investments in infrastructure, energy, water management, etc., planning solutions that are in line with the concepts of neutral land degradation and security;
- to establish more restrictive regulations on land use (e.g. to control the expansion of cities, the preservation of agriculture in peri-urban areas, and nature protection, etc.) through various instruments, most of which are binding.

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Climate Adaptive Agriculture: A Smallholders Case Study of the Southwestern Highlands of Ethiopia

Teowdroes Kassahun Teka and Svane Bender

1 Introduction

Millions depend on Ethiopia's food crops and livestock that are underpinned by its natural resources land, water and forests. However, climate change described in terms of variability and unpredictability puts the country in helpless position. Its high vulnerability derives largely from the country's heavy reliance on rain fed subsistence agriculture. According to the country's National Adaptation Program of Action (FDRE 2007), the country is very much heading to rainfall variability and temperature due to climate change, which could lead to increase in flood and drought. So far, the mean annual temperature has increased by 1.3 °C between 1960 and 2006. The Intergovernmental Panel on Climate Change (IPCC 2014) predicts the mean temperature to rise in the range of 0.9 to 1.1 °C by 2030, 1.6 to 2.0 °C by 2050, and 2.5 to 3.5 °C by 2080.

Climatic factors influence all aspects and stages of plant growth and affect agricultural productivity and food security. The growing impacts of climate change on livelihoods and different economic sectors of Ethiopia have compelled the Ethiopian government to develop the Climate Resilient Green Economy (CRGE) strategy as its main development paradigm (FDRE 2007). The CRGE is Ethiopia's national approach to climate mainstreaming. It sets out a framework for blending climate finance with development finance to maximise the effective delivery of climate objectives across sectors and regions. The strategy includes adaptation, mitigation and

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disaster risk management interventions, which are aimed at addressing vulnerability and food insecurity as a development priority. Accordingly, projects and programs that are in line with the CRGE strategy are considered of paramount importance to the country's growth and development.

When we consider agriculture and food security, the relationship between the three pillars of sustainability (economic, ecological and social) (Boyer et al. 2016) becomes more pressing. Degraded soils render farming almost impossible and economically unproductive with degraded soils; production is negligible. Hence farmers are faced with hunger and malnutrition, which further puts the natural resources under enormous pressure for further destruction. When this cycle of unsustainable exploitation of the soil for food production continues, it further limits the suitability of the area for further use (due to erosion, salinity, loss of organic matter etc.). Sustainable agriculture that can meet the food security challenges of providing for many people should at least maintain and promote soil fertility and enhancement. But the food security challenge is exacerbated further when external factors such as climate change and large-scale agriculture investment on lands that were previously owned by small holder farmers are taken. Interestingly, agriculture and climate change share a reciprocal relationship: There are several ways how agriculture influences or contributes to climate change, while on the other hand, climate change affects agricultural production (Kleemann 2012).

The Kafa area (or in terms of administration referred to as Kafa Zone) is located in the Southwestern part of Ethiopia with a population of more than 1 million with 130.14 inhabitants per km^2, is regarded as vulnerable to climate change due to a large portion of the inhabitants (90% small scale farmers) being dependent on subsistence farming (NABU 2017). Moreover, the ever-increasing population, poverty, internal migration, and expanding agricultural investments (large tea and coffee estates) have led to ecosystem degradation seriously damaging the genetic diversity of flora and fauna l within the ecosystem (Kumar et al. 2014). The selected four districts are part of the Kafa Biosphere Reserve (KBR). The KBR falls under the Hotspot of the Eastern Afromontane Biodiversity, with the site characterised by its "cloud forest" or the Afromontane moist evergreen broadleaf forest. This cloud forests are unique as they are home for the wild *Coffea arabica*. Because of its significant richness in biodiversity and important water catchment area the site has been included by the government as part of the Regional Forest Priority Area which puts it under the national protection (NABU 2017). In 2010, The Nature and Biodiversity Conservation Union (NABU), gave technical support (under the frame work of German public–private partnership) for the designation of the area as UNESCO biosphere reserve.

In 2010, the area was designated as UNESCO biosphere reserve, which has been planned under the technical guidance of The Nature and Biodiversity Conservation Union (NABU) in the framework of a German public–private partnership project.

The local population, mainly dependent on natural resources and various ecosystems services, is already experiencing the impact of climate change. Nowadays, the effects of climate change on agriculture and forest coffee populations have started to be noticed by experts and the local population. The influence from external actors in terms of new technologies and interests also brought changes in land use management, affecting the biodiversitys as well as the ecosystem services (NABU 2017).

At the same time, traditional knowledge of ecosystems, sustainable cultivation systems, and traditional use methods are at risk of being lost especially among young people, and the future generation.

Against this background, NABU, initiated a study to identify existing and potential effective climate change adaptation practices of small-scale farmers in the KBR for test piloting programme. This paper firstly presents the main results of the study addressing the following questions: (1) What are the most frequent and damaging effects of climate change on land use, especially agriculture in the KBR? (2) Which local or traditional agricultural practices are currently applied to adapt to the changing climate? Secondly, the paper will showcase the piloted measures for sustainable, tailor-made farming practices for climate resilience and supporting sustainable income opportunities for small-scale farmers targeting long-term food security.

2 Methodology and Data Collection

2.1 Study Site

Kafa is located in the Southern Nations Nationalities and Peoples Regional State (SNNPR) and is divided into eleven districts (NABU 2017). The study was conducted in four of the eleven districts (Woredas), Adiyo, Gimbo, Decha and Sayilem. The altitude ranges from 1020 m.a.s.l. to 3350 m.a.s.l. The climate is typical for the region with annual temperature of 19.45 °C and annual rainfall 1800 mm with rainy season between June and September (Dresen 2014).

Subsistence farming is the main livelihood for large segment of Kafa zone communities coupled with sale of wild coffees and natural resources (such as construction material, medicinal plants, honey etc.). Land use in Kafa has been in harmony for centuries with the tradition and customs in line with nature and the environment. Unfortunately, the rising population and immigration form other parts of the country coupled with large scale agro-investments (e.g. eta, coffee) putting immense pressure on the natural resources of the region. Apart from the sale of wild coffee (10% of the whole coffee production area) and honey, the local population is strongly dependent on small-scale subsistence farming in home gardens and small fields, as well as on the natural resources provided by their environment for food, fuel, building materials, medicinal plants/ spices and fodder. *Eragrostis teff* is the main local grain species that is cultivated in the area. In addition, to garden coffee (65% of the entire coffee production area), legumes and the locally important *Ensete ventricosum* are cultivated, whose starch-rich stem and tubers are fermented to make bread. Around 25–35% of the income of households with access to the wild coffee forests is derive directly or indirectly from the sale of coffee. The most usual livestock are cattle (7.5 per household, 2011/2012), followed by poultry, sheep and goats. In times of need, residents turn to wild plants from the forests and wetlands for food supplies.

2.2 Data Collection and Analysis

The sampling site selection of the four districts located within the KBR took into consideration agro-climatic zones, farming practices in the area, types of livelihood and population density. Following the site selection, a household survey was conducted in June 2018. A systematic sampling method was used to select a total of 50 farmers from the four selected districts. The questionnaire developed for this study was pre tested using selected framers from different district of the study area. Furthermore, participatory methods such as trend analysis, seasonal calendar was used to guide focus group discussions (12 focus groups). For detailed information gathering key informant interviews were conducted with knowledgeable persons and experts in the area.

Secondary data for each district were collected from the local agriculture offices focusing on land-use, types of crops, livestock extension activities, food security and natural resources management. Rainfall maximum and minimum temperature were taken at five geo-referenced points. The gridded rainfall time series data which was validated by Reading university, UK, was primarily reconstructed from NOAA (MODIS) satellites by the Ethiopian Metrological Agency and the International Research Institute for Climate and Society at Columbia University, USA, which were later calibrated and validated by Reading University, UK. A strong correlation ($r = 0.8$) was observed between the result from the reconstruction and the station and satellite derived data. This result confirmed the reconstructed data are reliable and valid for analysis of climate variability and trends in the country. The rainfall data used in this study cover 1983 to 2014.

The spatial extent for rainfall was analysed using the monthly rainfall data of each geo-referenced point that were derived using interpolation by the Inverse Distance Weighted (IDW) method. This method was chosen due to its better representation of interpolated data across different topography that are mostly heterogenous (Tagel et al. 2011). The analysis was conducted using ArcGis.

To analyse the variability in rainfall, Standardized Rainfall Anomaly (SRA) was used (Agnew and Chappel 1999). SRA was computed as the difference between the annual total of a particular year and the long-term average rainfall records divided by the standard deviation of the long-term data. This index is used to evaluate the inter-annual fluctuations of rainfall in the study area over the period of observation, which is given as:

$$\mathrm{SRA} = (\mathrm{Pt} - \mathrm{Pm})/\sigma$$

where

SRA is standardized rainfall anomaly,
Pt is annual rainfall in year t,
Pm is long term mean annual rainfall over a period of observation and
σ is standard deviation of annual rainfall over the period of observation.

The same method was applied to compute the temperature anomalies.

3 Results of the Study and Discussion

The rainfall pattern across Kafa Zone was similar for most of the years 1983 to 2014. Using seven sample years with five interval years, the patterns were depicted. For instance, in 1983, except some of the central parts, large parts of Kafa received rainfall ranging between 1840 and 1995 mm. However, in 1998 the rainfall distribution showed a distinct and a declining pattern moving from west to east. In 2003, northern districts received higher rainfall than the southern districts, while in 2008 and 2014, there were distinct patterns of rainfall distribution. Generally, most districts of Kafa received the highest rainfall in 1988, compared to other years. On the contrary, most areas received less rainfall amount in the years 1993 and 2003. Except in the 1998, north-western districts had a better rainfall distribution than others parts.

3.1 Analysis of Metrological Data (Precipitation and Temperature) at Four Districts of Kafa Zone

Precipitation

The Standardized Rainfall Anomaly (SRA) method was applied for analysing variability of rainfall. The years 1984, 1986–1987, 1994–1995, 2000, 2002–2003, 2007, 2011–2014 had a mean annual rainfall below the long-term mean annual rainfall (Fig. 1). The positive and negative trends observed in the rainfall data indicate rainfall variability in the study area. During 1983–2014, all referenced points have a mean annual rainfall above the long-term mean annual rainfall in the years 1992, 1997, 2006, and 2008. This indicates there were spatial variations in the mean annual rainfall across the geo-referenced points (Fig. 1).

Study sites Gimbo, Adiyo and Sayilem (Fig. 2) showed increasing trends of annual rainfall ranging from 5 mm per decade in Sayilem to 36 mm per decade in Gimbo during the study period. On the contrary, Decha showed a slight declining trend of annual rainfall (1.6 and per decade). In recent years although they show different magnitude of change in the trends of annual rainfall, all geo-referenced points have annual rainfall below their average. There was no any systematic pattern in the trends of average annual rainfall across all geo-referenced points in the study time scale (1983–2014).

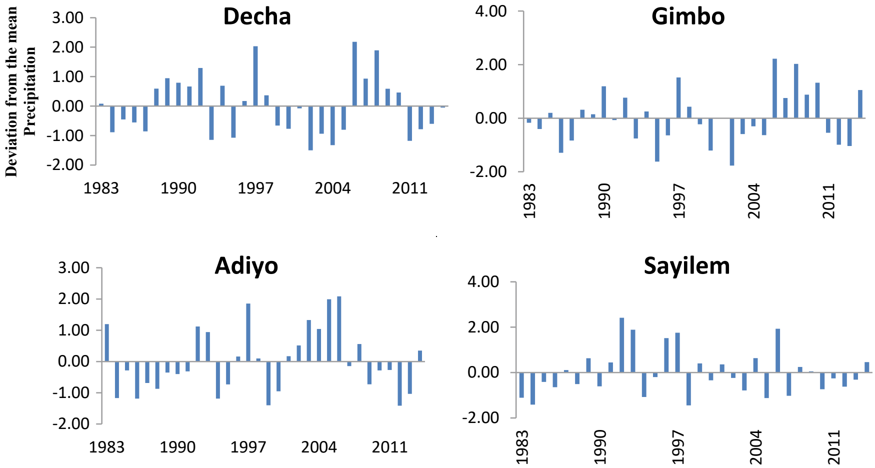

Fig. 1 Annual precipitation anomalies for the districts of Decha, Gimbo, Adiyo and Sayilem in the Kafa zone from 1983–2013. *Source* NABU

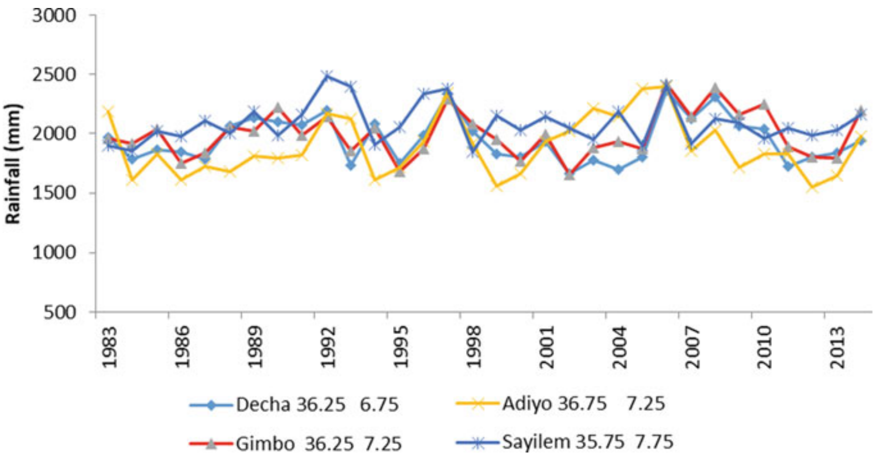

Fig. 2 Trends of annual rainfall in five geo-referenced points 1983–2014. *Source* NABU

Given the fact that 90% of food production in Sub-Saharan Africa is largely produced by small-scale farmers dependent on rain fed agriculture (Rosegrant e al. 2002), variability in rainfall is quite devastating for productivity as well as food security. The variability of rainfall in Kafa is similar with various parts of Africa (e.g. Tanzania, Uganda and Ghana) reporting overall decline in rainfall or significant variability (Ojoyi et al. 2015; Diem et al. 2017; Teye et al. 2015).

Fig. 3 Annual maximum and minimum temperature anomalies for Adiyo, Sayilem, Gimbo and Decha districts in 1980–2016. *Source* NABU

Temperature

From 1980–2001, the mean annual minimum temperature of all the geo-referenced points was below the long-term mean annual minimum temperature, except for 1987, 1995, and 1996. Especially, in 1999, all geo-referenced points had mean annual minimum temperature three times less than the standard deviation from the long-term mean minimum temperature (Fig. 3). However, since 2001, the mean annual minimum temperature was above the long-term mean annual minimum temperature of the points. The mean annual minimum temperature in all points showed slight increasing trend with 0.2 °C per decade.

There was a big temporal variation of maximum temperature anomalies across the study points (Fig. 3). For all years prior to 1995, the average annual maximum temperature of all geo-referenced points was below the long-term average annual maximum temperature. Since1995, the pattern has reversed. When we investigate the spatial variation of maximum temperature, there were systematic changes across the geo-referenced points. Warming trend in the study area was indicated by the irregularities for maximum and minimum annual temperatures which is in an increasing trend.

3.2 Farmers' Perception on Climate Change

Farmers in the four districts perceive a long-term change in their local climate. They decisively state that the rainfall amount has been declining continuously and rainy seasons are starting very late compared to the past years. This made it very difficult to follow the usual cropping calendar they have been following for decades. The farmers claimed that this has brought tremendous challenge to them and they are facing

Table 1 Major statements by farmers in relation to the changing climate

	Comments by the farmers	Impact
1	"The old cropping calendar is not working anymore"	Loss of yield
2	"Delay to onset of rainfall"	Difficult to prepare the land for planting
3	"We are facing more often erratic rainfall"	Crops are damaged sometimes totally at the early stage
4	"Food shortage in the summer and less income"	Forced to do daily labour jobs in the neighbouring districts
5	"Traditional or typical cereal crops are getting lost and not enough is produced"	Farmers are more and more dependent on *Ensete ventricosum* as the main source of food

Source NABU

significant declines in agriculture productivity, forcing them to look for alternatives to bridge the loss in agricultural production (Table 1). The farmers strongly pointed out that due to decreased production, their household income is at risk, forcing many of them to work as daily labourers. This trend also makes framers fearful with the possibility of losing some of the traditional seeds such as *Eragrostis tef* largely due to unfavourable weather conditions (e.g. moisture stress, shifting rainy seasons).

Most of the farmers believe that the rainy season is shifting and is becoming more unreliable in the last years. The majority of farmers pointed out that decreasing soil moisture and increasing heat are among the most serious challenges during the cropping season. Kassahun and Bender (2020) described similar results at the KBR, where farmers reported decreasing rainfall, moisture stress and heat waves, which was confirmed by metrological data. It is not surprising that farmers tend to evaluate climate change in relation to variability, which they normally observe in their environment (Kofinas 2002). As cropping or planting is directly related to the commencement of the rainy season, many farmers can easily see direct changes.

The rainfall data analysis shows no pattern across the studied geo referenced points. In another study the overall rainfall for the entire KBR (across a 50-year data) showed a declining trend (Kassahun and Bender 2020). This mismatch is not unique to the area. Similar studies focusing on perception of climate change have reported a mismatch between metrological data and farmers' perception. The reasons could be attributed to the facts that: (1) it is quite easy to describe changes over a short period of time compared to a long-term period (Orlove and Roncoli 2006); (2) since all respondents in the survey were farmers, they may have concluded the climate is abnormal and changing as long as it does not fit their cropping calendar or if they incurred loss in yields (Slegers 2008; Grothmann and Patt 2015); (3) farmers are more focussed and judge about rainfall availability during their traditional cropping months rather than the total amount of rainfall received annually and (4) farmers perception is maybe largely affected by recent incidents or events rather than long-term trends (Bryan et al. 2009). Farmers in the northern districts are less likely to notice an overall decline in annual rainfalls than the southern districts.

Studies by Inglod and Kurttila (2000) and Quinn et al (2003) explain the difference in spatial variation in perception due to location, available technologies and the predominant subsistence activities. However, the sites selected for this study do not have a significant difference in available technologies as well as farming activities. The likely reason why the southern part perceives more changes could be the dry spells occurring more frequently than in the north of Ethiopia.

3.3 Climate Adaptation of Agriculture for Food Security

In general, the farmers regard the changing climate in their area as a very significant threat to their livelihood. Due to difference in the micro-climate across the Kafa Zone (higher, middle and lower altitudes), there will also be a difference in the impact from climate change as well as the possible adaptation measures taken. Table 2, describes the most frequent climate change indicators mentioned by the farmers across the four districts and potential adaptation measures the farmers are taking as a response to the challenges. The observation by the farmers on the changing climate is typically reflected by its actual effect on their livelihood (Berkes et al. 2002).

Taking into consideration the results from study described above as well as other food security related research results and monitoring data, a test piloting of climate adapted agriculture and livelihoods has been initiated in KBR. The holistic approach was meant to meet the current and predicted impacts of climate change, the population's needs for food security and requirements of the specific conditions in a UNESCO biosphere reserve, where land use ought to be merely sustainable and of no damage to natural resources. The test piloting targeted different angles of food security and was based on participatory consultation processes (some of them described above).

3.3.1 Reintroduction of Climate Adaptive Old Crop Varieties

The KBR is rich in forests, grasslands and wetlands. Its ecosystems offer a great variety of non-timber products including edible fruits, mushrooms, plants etc. Over time, people have cultivated and thus indirectly changed the characteristics of many plants. Among this plant some have been well adapted to farmers home garden as well as in farm lands providing much needed food within the household and for cash. The typical Ethiopian cereal diet lacks the basics nutrient or vitamins, hence the wild fruits or berries collected from the wild supplement the nutrient deficient diet. A report from FAO indicates significant percentage (90%) of crops are forever lost largely those crops that are found on smallholder farmers land. These losses are further exacerbated by the continuous destruction of ecosystems (forests, wetlands and other wilderness areas) and genetic diversity. However, untapped potential for energy, food and alternative income opportunities exist and remain abandoned including well adapted crops that could contribute for food security and biodiversity (NABU n.d). Therefore,

Table 2 Climate change and adaptation measures taken by farmers

Climate change indicators	Trend	Adaptation measure currently taken by local farmers
Frost	Average temperature increased over the last 10 years. But frost cannot be explained by yearly trend of temperature. Rather, it is the daily variation that can describe when and for how many days exactly frost has occurred	– Diversification of crops; – Homestead farming with a variety of food and cash crops such as tuber and root plants; – Planting Ensete ventricosum, fruit trees, eucalyptus trees around their homestead; – In the highlands sheep rearing becoming an element of the mixed farming system
Hailstorm combined with torrential rain	Farmers perceive its occurrence as unpredictable and no long-term trend could be detected	– Diversification of crops by including perennial crops in their agricultural practice
Excessive rain	High amount of, intensive, and extended period of rainfall occurring more often	– Furrowing, contour farming, and planting grass along the contour – Soil and water conservation measure along the slope – Furrowing is done by shifting every crop season rotating on their land to trap the soil and water from their farms and use their land efficiently – Leaving crop residue on the farmland is also another traditional practice – Strip cropping
Late onset of rainy season	Frequently occurring phenomenon at all visited districts. Particularly in areas where Maize is grown widely, the shift is up to two months (from end of December to beginning of March)	– Changing of the growing calendar. The focused group discussion shows that the growing calendar of maize starts normally in late December but nowadays it is pushed towards March or to the beginning of April
Untimely rain falls	Rainfall in early May is not common	– The traditional technique of drying and protecting of freshly harvested crops
Landslide	Not commonly occurring	– No clear adaptive response to the incidence of landslide, considering that it is a rare occurrence

(continued)

Table 2 (continued)

Climate change indicators	Trend	Adaptation measure currently taken by local farmers
Crop pest	Farmers mention that fungal disease on Eragrostis tef (Teff), Triticum sp (Wheat) and Zea mays (Maize), becoming more frequent in recent years. It occurs when there is no adequate rain	– Adjusting the cropping season by resorting to early planting, following the first rains after repeated ploughing – Changing the crops that are affected Vicia faba (bean) and Pisum sativum(pea) – Expanding the Ensete ventricosum plantation with different varieties at their homesteads – Diversifying the crops both in the field and in their homestead – Planting more cash crops such as Coffea Arabica

Source NABU

NABU initiated an in-depth study on potential climate adaptive crops in the KBR for identifying suitable crops which could be (re-)introduced to contribute to food security and agricultural biodiversity (Kassahun and Bender 2020). The reintroductions can contribute for climate adaptation and improve biodiversity ensuring the food security of local communities. More than 70 local species were recorded through interviews, home gardens surveys and consultation of spiritual leaders in the region. Finally, five species that fulfilled the criteria of being well adapted to the current impacts of climate change such as drought and heavy rainfall were selected: *Brassica cannata* (gawusho), *Ensete ventricosum* (enset), small pumpkin (gishi buqo), *Eruca vesticaria* (dawureche bruce) and *Colocasia esculenta* (taro). More than 4500 seedlings were test planted with more than 180 local women for pilot cultivation and evaluation. After the successful testing phase, the organisation started a promotion campaign in close cooperation with the local agricultural authority, including workshops with local communities, farmer-to-farmer exchange of experiences between the participating women and more than 250 additional women, and the development of a handbook, poster and brochure on the importance of the introduced five species and agro-biodiversity in the local language.

3.3.2 Promotion of Organic and Climate Change Adapted Agriculture

In the Kafa Zone, majority of the population depend on agriculture as the main source for income and food. But is also well understood the impact agriculture has on natural ecosystems. Farmers at KBR are suffering from a lack of knowledge on how to improve agricultural production while respecting UNESCO biosphere reserve's principles on sustainable agriculture while increasingly suffering from the impacts of climate change on crops and ecosystems at the same time. Building up the capacities of farmers and agricultural departments would eventually lead to an improved small-scale organic agricultural production under climate change and thus enhance people's livelihoods.

Currently there are more than 120 countries practicing organic agriculture since its inception in 1972. The International Federation of Organic Agriculture Movements (IFOAM) defines Organic Agriculture as "a production system that sustains the health of soils, ecosystems and people". It is a different form of farming without the destructive use of external inputs, and relies on ecological processes and cycles that are well adapted to local conditions. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved." (NABU 2020b). The main attraction for organic framing is its contribution to productivity and high price for products with certification and marketing. NABU therefore decided to introduce organic agriculture to Kafa Zone and in particular to the KBR by introducing knowledge to experts to assist framers in transitioning to organic farming. To support this transitioning a guide and reference book were elaborated with experts from University of Natural Resources and Life Sciences, Vienna (Austria) based on consultations and trainings with local farmers offering training material which also can serve teachers, students and scientists. Several demonstration plots were established where farmers were trained and could regularly see results and learn (farmers to farmers exchange). The guide book, being the first for that area, provides extensive knowledge to agricultural advisors that guide farmers in the transition from conventional farming to organic farming tailor made to local conditions. The involvement of local specialists and biosphere reserve rangers, enhanced the quality, applicability and increased the likelihood of adoption by farmers. To showcase an efficient farm management and secure sustainability technical methods of organic farming that help to increase the soil fertility and yields of crop were demonstrated in several small micro demo-farms that were established on existing farming plots. Altogether, 750 conventional farms have been transitioned to organic farming. Given the potential improvement of the nutritional situation of the rural farmers that are typically neglected and forgotten, organic farming provides them a chance to increase their production with the limited resources they have and minimize their production risk by increasing and promoting diversification of their cultivation system, and therefore enhance their chance to adapting to climate change.

The following section will present some of the concrete measures taken addressing specifically the locally critical issues:

1. **Limited amount of humus in soil**: Generally, in tropical climate approximately 10 t of dry matters ha^{-1} a^{-1} biomass production is required to sustain the humus content in soils. The biomass production in current smallholder farming systems in the study area is only 5 t ha^{-1} a^{-1} (NABU 2020b). Hence crop rotation systems with different crops that are important for humus production were introduced with further information on how much biomass can be expected within two

Table 3 Crop rotation-based characteristics for humus production

Year (two seasons)	Crop rotation	Acres	ha	Root biomass		Humus balance	C/N	Mineralisation
				kg DM ha^{-1}	kg DM a^{-1}			
1	Alfalfa	1.07	0.27	5000	1338	+++	10/1 –30/1	+ to +++
2a	Maize	0.28	0.07	500	35	0	30–50/1	(+)
	Maize	0.80	0.20	500	100	0	30–50/1	(+)
2b	Grain legumes	1.08	0.27	750	203	+	15/1	+++
3a	Teff	0.97	0.24	500	122	+	25–35/1	+
	Teff	0.12	0.03	500	15	+	25–35/1	+
3b	Potato	1.08	0.27	300	81	–	10/1	+++
4a	Vegetables	0.80	0.20	500	100	–	10–30/1	+++
4b	Herbs	0.28	0.07	300	21	–	10–30/1	+ to +++
	Napier grass	0.58	0.15	1000	146	+ to ++	25/1	+
	Pasture	1.46	0.37	1500	548	(+)	15–30/1	+ to ++
	Alley branches	0.49	0.12	3000				
Total		**6.85**	**1.71**	**2,838**	**677**			

Source NABU (2020b)

farming seasons (Table 3). Furthermore, legumes and alley crops will play a critical role in atmospheric nitrogen fixation and biomass production.

2. **Soil erosion**: Formerly, the area of KBR was almost fully covered by Afromontane cloud and rain forests. Because of this forest cover, potential soil erosion due to rain and sunrays is minimized. In the last decades, the forest cover has been disturbed due to unregulated forest destruction for exploitation, agro-investment and peoples need for livelihoods. This led to critical soil erosion in some areas. Farmlands that are temporarily covered with plants or totally exposed are expected to lose soil between 20 and 200 t ha^{-1} a^{-1} soil can be lost (NABU 2020b). Stopping erosion can be done implementing cropping strategies with some technical measures. Hence a combination of technical and cropping strategies was applied: (I) Technical erosion control for areas where erosion is in an early phase (promoting crop rotation); intercropping or under-sown forage legumes (e.g. maize with beans, potato with beans).of crops with a row distance of 50 cm or more; integration of leguminous alley crops and Enset in the cropping/ fruit/ coffee system as mulch material; addition of local mulch material) (II) targeted management for eroded areas (trench digging; stabilisation of trenches with diverse crops, combining deep rooting trees with grass

types; reallocation of accumulated soil to higher areas where the soil was eroded from).

3. **Soil water management**: to enhance the soil water of the area, a combination of technical/agronomic practices was introduced depending on the specific site conditions (Table 4).
4. **Diversification of cropping systems**: Although the area has high potential to cultivate diverse crops and by doing so for enriching biodiversity and contributing to minimized soil erosion, a diverse cropping system (intercropping, crop rotation) is missing. A detailed strategy was developed detailing the sowing and harvesting period, altitude requirements and techniques for selected arable crops.

The guide book was presented to the respective government representatives for adoption and implementation; the test farming is still ongoing.

3.3.3 General Improvement of Local Agricultural Practice

Based on previous project results, consultations with smallholder farmers, local governmental experts, the biosphere reserve rangers and several studies (e.g. Kassahun and Bender 2020) on climate change impacts (see above) and agricultural methods in the area, NABU developed a basic manual for small-scale farmers, how to best cope with the current climate change impacts. Following the manual, hundreds of farmers participated in training and pilot implementation. More than 30 model farms were established to promote the measures and pass knowledge to farmers who did not participate in the trainings. Moreover, the trained farmers were expected to pass on their knowledge to at least 10 more farmers, through this local upscaling 7500 farmers have been reached. To reach further target groups in the area, agricultural department development agents were included in the exchange of experiences.

3.3.4 Enhancement of Green Value Chains for Additional Sources of Income

To support climate change stricken small-scale farmers by opening up opportunities for additional, sustainable income sources, amongst other, forest related programmes, female farmers were engaged into production of local green products. Through a survey, promising regional green products e.g. *Piper capense, Aframomum corrorima*, *Lemon verbena, Coffea arabica, honey, Capsicum annuum L.* and *Bidens macroptera* were identified for production and marketing.

Then, more than 230 farmers from five producer groups, the majority of them women, were trained in sustainable cultivation and harvesting methods as well as processing, packaging and marketing of selected products in order to further increase local value creation. In addition, an international entrepreneurs' scouting

Table 4 Agronomic/technical based practices to soil water management

Agronomic/technical based practices	Characteristics
Hedge and alley systems in the surroundings of the fields	• Retain water around them as they slightly decrease the temperature and evaporation • Cuttings spread over the fields increase the organic matter (OM) content of the soil and thus increase water holding capacity
Mulching	• Achieved by leaving crop residues on the field or by transferring plant residues from trees and hedges or from other fields or pastures (transfer mulch) • The goal is to produce enough fodder for livestock to reduce stubble grazing, which leads to soil compaction and humus loss
Manure and/or compost, alley branches	• Application of manure/compost is key to building and sustaining soil fertility and thus water holding and infiltration capacity of the soil • OM and nutrient delivery by manure/compost is underestimated by many farmers
Biochar	• Mixing biochar in planting holes of e.g. coffee • Incorporating biochar across the whole field
Tillage reduction	• Shallow tillage
Contour tillage and graded furrows contour tillage	• Effective water conservation practice • Avoids water erosion, but also conserves water as the ridges formed by tillage hold water on the land, which increases the time for infiltration
Basin tillage (tied ridging)	• Formation of small earthen dams in furrows to trap rainfall, thereby preventing runoff and providing more time for infiltration
Land smoothing	• Uneven land hinders mechanisation, increases weed development and leads to lower plant growth • Land smoothing serves to move soil from high to low points in a field • When low points are eliminated, water is prevented from concentrating at them; this creates more uniform storage of water in the field for the next crop • Land smoothing should not eliminate small-scale surface depressions if these allow water to be stored temporarily rather than running off
Terracing	• Various types of terracing have been developed that provide soil and/or water conservation benefits

(continued)

Table 4 (continued)

Agronomic/technical based practices	Characteristics
Improving irrigation efficiency	• Optimised management of irrigation water would increase yields up to 100–200%, but care and emphasis must be given as to when and where to construct irrigation infrastructures, and how the activity avoids also land degradation • Irrigation efficiency can be enhanced by: appropriate conveyance systems (using water-tight materials, proper canal gradients, etc.), as well as appropriate water application systems (such as drip irrigation or furrowing), improved irrigation calendars (such as managing deficit irrigation and selecting proper cropping patterns, such as double-row planting) • Water collection from roofs, regulation of runoff water, and water storage for household needs or nearby vegetable gardens, are techniques with low investment and labour costs; adapted solutions are household specific • Many farmers can, with little effort, increase vegetable and fruit tree yields at about 50–200%; furthermore, the vegetation period towards the dry season can be extended for approx. 1–2 months

Source NABU (2020b)

tour was organised with companies from 13 international and Ethiopian environmentally conscious companies, press and academia. Farmers and producer groups were visited, so that buyers could see availabilities and qualities. This opened direct market access to buyers from Ethiopia, Canada, Germany and the USA. Due to the tour producers and buyers-initiated business relations and products such as beeswax, Koseret (*Lippia abyssinica*) and Ethiopian cardamom (*Aframomum corrorima*) were sold. Due to this market linkage, further national and international companies could be attracted as buyers (e.g. tea, coffee).

To fill gaps on quality (storage and drying) in the value chain, a storage and processing hall was built by NABU for the farmers. Moreover, to be able to reach even more farmers in the future, a training manual was produced that is explicitly aimed at employees of the local agricultural authority and assigned development agents, so that they can integrate the topics into their ongoing work with the farmers.

4 Conclusions

Climate change and its impacts are increasingly reported across the country with disproportionate impact on small hold farmers who are still heavily dependent on rainfed agriculture. Although there was not any systematic pattern regarding precipitation or temperature, we saw significant variability. The small hold farmers located within the KBR also perceive a change in their climate and variability in precipitation. Hence, farmers are forced to look for alternatives and to adapt.

Overall, there is a high demand to transition smallholder farmers in the KBR to agricultural systems that is well adapted to the changing climate and improve food security. The multiple pillared programme piloted by NABU has been very well received and accepted both at farmers and local governmental level. The approach of practical training at farmers level with demonstration plots, model farms, farmer-to-farmer exchanges guide books and manuals for both the farmers but also the representatives of the local government engaged in agricultural departments turned out as very successful for adoption, sustainability and further upscaling.

About 7500 smallholders from KBR were reached for improvement of agricultural production in terms of climate adaptation. The introduction of organic farming provided opportunities to address several inefficiencies within the smallholder farming system with simple interventions. Nevertheless, to increase future food security, all programme components will require further local and regional upscaling and advisory support from NGOs like NABU, in particular with respect to new or additional challenges for farmers and international business relations such as the COVID 19 pandemic. The presented method shows high potential for upscaling in other regions of Ethiopia and beyond and can be tailor-made to local conditions, farming systems and stakeholders.

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Differentiated Intra-Household Food Utilisation in Raymond Mhlaba Local Municipality, South Africa

Saul Ngarava, Leocadia Zhou, Thulani Ningi, and Martin Munashe Chari

1 Introduction

Ensuring dietary needs and food preferences is central in ensuring food security through utilisation (Taruvinga et al. 2013). The unit of analysis in ensuring food utilisation varies from continent, region, nation, community, household to individual levels. The smaller the unit, the greater the emphasis is on individual solutions (Flora 2010). Food utilisation relates to the ability of the body to process and use nutrients considering the dietary quality and food safety (Perez-Escamilla 2017). According to the World Health Organization (WHO 2021), many women and children across the globe are at risk of malnutrition. This has resulted in a global population with 462 million adults who are underweight, 47 million children under five years who are wasted and 45% of deaths occurring among children under five years of age (WHO 2021). The CDC (2020) highlights that globally, 1.8 billion people have insufficient iodine intake, 17.3% of the population is at risk of zinc insufficiency and half of the children under the age of five years suffer from vitamin and mineral deficiencies. However, some of these deficiencies are not due to lack of food, but to poor diet decision-making. This has resulted in an accelerated rate of overweight and obesity, another form of malnutrition through food utilisation (WHO 2021).

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The staggering number of malnourished people world-wide resulted in the establishment of the Sustainable Development Goals (SDGs) (Sharma 2020). SDG 2.1, in particular, endeavours to end hunger and ensure access to safe, nutritious and sufficient food by the year 2030 (Mugambiwa and Tirivangasi 2014). This works in tandem with SDG 2.2, aiming to end all forms of malnutrition and SDG 2.4, targeting sustainable food production systems. To meet the objectives of SDG 2, there is a need for innovations and new development in food production and consumption.

In South Africa, there is food security at the national level, but food insecurity at the household level (Oluwatayo 2019; Raidimi and Kabiti 2019). High levels of poverty and inequality have resulted in this. According to de Klerk et al. (2004), by 2004, 14 million South Africans were suffering from food insecurity, 43% of households were suffering from food poverty and 1.5 million children had malnutrition. By the year 2015, Walsh et al. (2015) highlighted that 26% of households in South Africa were food insecure, whilst 28.3% were at risk of being food insecure. In a more recent report by IPC (2021), it was indicated that 8.18 million people in South Africa were in crisis and 1.16 million were in a state of emergency in terms of food insecurity by December 2020, with a projection to increase to 9.60 million and 2.20 million by March 2021, respectively. The main drivers of this increase in food insecurity included the COVID-19 pandemic, economic decline and unemployment, food prices, and drought (IPC 2021). Even though numerous studies on food security have been conducted in South Africa (Ndhleve et al. 2012; Haese et al. 2013; Walsh et al. 2015), they have tended to ignore the food utilisation aspect of food security.

What is evident from both under and over nutrition scales is the inherent decision making, be it voluntary through consenting adult or involuntary through guardianship (Nepper and Chai 2016). Perez-Escamilla (2017) identifies that one of the causes of inadequate food utilisation is the limited economic access to food. Adopting measures to increase household purchasing power is key to improving food availability, access and utilisation (Pawlak 2020). The inability to purchase food can be circumvented by producing it. This is particularly significant for micronutrient utilisation. Smallholder agriculture enables food utilisation, through improving dietary patterns in rural areas (Oluwatayo 2019). The decision of whether to purchase or produce food tends to have an effect on food utilisation. The intrahousehold responsibility of producing or purchasing food will affect the food security status of the household.

Food production has a consequence for sustainability. Issues of sustainability acknowledge the need to combine equity, profitability, and to ensure a healthy environment (Sharma 2020). Sustainable agriculture endeavours to meet intergenerational equity. Home gardens have been identified as engines for sustainable agricultural systems (Amenu 2017). However, Acharya (2006) argues that this possesses a trade-off between alleviating the current generation of food insecurity and caring for the future.

There is a need to shift to more localised small-scale production relative to corporate controlled industrial agriculture (Baksi 2019). However, even at the smallholder or household levels, there are differentiated decision makers and role players in terms of food availability, access and utilisation. Male heads tend to concentrate on food purchasing, whilst female heads and women tend to concentrate on cooking chores.

Home gardening is also divided amongst men and women within the household. These prescribed responsibilities tend to influence the particular food utilisation that is experienced within the household based on the responsibilities and role-playing.

Sustainable home gardening also has roots in the person responsible for the garden. This also tends to affect the food utilisation, depending on the food that is produced from the garden. According to Taruvinga et al. (2013), home gardening has had a positive influence on dietary diversity. Thus, there are various food utilisation scenarios determined by household responsibilities. Furthermore, they play an integral part for in-situ conservation of agricultural biodiversity. However, home gardening has often been unrecognised and overlooked due to its small size (Legesse et al. 2016; Khanal and Khanal 2017). Therefore, the chapter seeks to highlight the roles that different household members have concerning food utilisation, zeroing in on how sustainable home gardening may be central to food utilization. The study hypothesised that there are differences in household role-playing for food utilisation.

2 Methodology

2.1 Study Site

The study was carried out in Mavuso village (Fig. 1), located in Raymond Mhlaba (formerly Nkonkobe) Local Municipality. The municipality is located in Amathole District Municipality in the Eastern Cape Province of South Africa.

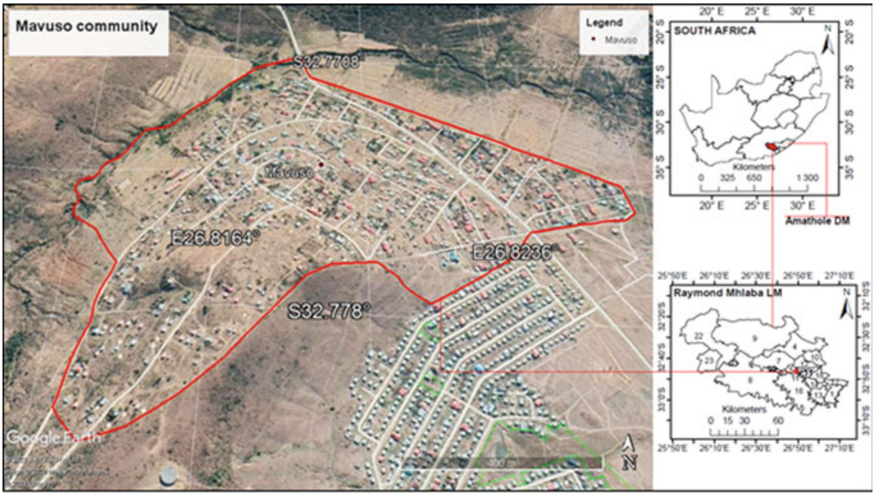

Fig. 1 Study site (Google Maps 2021)

Mavuso village is located 3.6 km away from the nearest town, Alice, and 6.5 km from the University of Fort Hare. According to StatsSA (2011), the population of Mavuso village in the 2011 census stood at 1188, with a total area of 0.70 km^2. There are 334 households in Mavuso, with half the population being female. Forty-eight percent of the population in Mavuso is under 35 years of age, with 96.88% being Xhosa speaking (StatsSA 2011). There are high unemployment and poverty rates in Raymond Mhlaba Local Municipality at 68% and 71%, respectively. Livestock production is the significant economic activity in the area (Musemwa et al. 2018).

2.2 *Study Design*

The study utilised a household cross-sectional survey. Simple random sampling was utilised in the study. From a total population of 334 households in Mavuso village (StatsSA 2011), the Yamane (1967) method was used to calculate the sample size:

$$n = \frac{N}{1 + N(e)^2}$$

where n is the sample size, N is the population and e is the confidence interval. The following sample size was then obtained

$$n = \frac{334}{1 + 334(0.05)^2}$$

$$n = 182$$

A structured questionnaire was distributed to 182 households targeting the household head, or any other person above 18 years old. However, after data cleaning, only 116 questionnaires were eligible for further analysis. In estimating and testing the hypothesis of differences in role-playing for food utilisation, descriptive statistics and cross-tabulations were utilised in analysing the 7-day recall nutrition survey data.

3 Results and Discussion

Table 1 shows that the average age of the respondents was 58 years, with household sizes averaging 4. There were fewer youth in the households for both men and women, with women aged 36 years and older constituting the largest proportion in the households.

Table 1 Descriptive statistics

	Min	Max	Mean	Std. Dev
Age	25	103	58.41	14.029
Household size	1	15	4.32	2.714
Women 36 years and older	0	3	1.19	0.715
Men 36 years and older	0	3	0.83	0.701
Women 19–35 years	0	4	0.52	0.818
Men 19–35 years	0	4	0.44	0.738
Women 18 years and younger	0	5	0.67	1.002
Men 18 years and younger	0	4	0.70	0.938

As illustrated in Fig. 2, at the time of the study, more than 72% of the respondents had been resident in Raymond Mhlaba for their entire lifetime, whilst 12.2% had been residents for between 21 and 30 years.

The educational levels of the head of household as depicted in Fig. 3 indicates that, at the time of the study, 41.7% had Grade 12 (Standard 10) while only 1.7% had reached Degree level. Table 2 highlights that, when the study was conducted, female heads in Raymond Mhlaba Local Municipality were responsible for the cooking, buying of food, and home gardening. Wives were also responsible for cooking, while male heads also dominated to buying the food and assisting with home gardening.

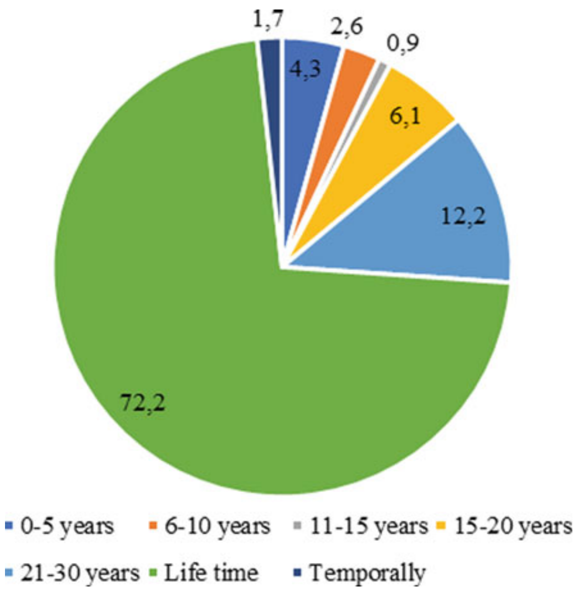

Fig. 2 Duration of residence in Raymond Mhlaba Local Municipality

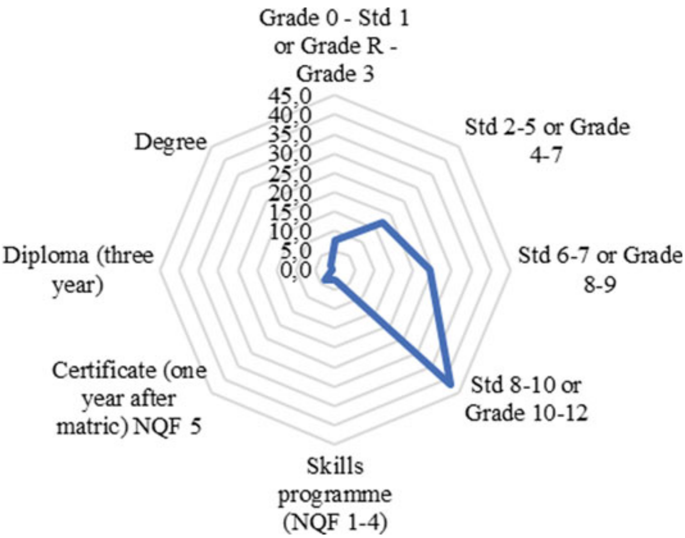

Fig. 3 Educational levels of household heads in Raymond Mhlaba Local Municipality

Table 2 Differentiated responsibilities in cooking and buying food as well as home gardening based on intra-household roles

Household role	Responsibility		
	Cooking (%)	Buying food (%)	Home garden (%)
Male head	16.7	21.9	21.6
Husband	6.1	14.0	17.1
Female head	36.8	39.5	29.7
Wife	22.8	14.0	4.5
Married daughter or daughter-in-law	1.8	1.8	
Young teen mother	0.9	0.9	2.7
Girl child	3.5	0.9	1.8
Yourself	8.8	6.1	15.3
Any other person	2.6	0.9	7.2

The pecking order in serving food shows that 48.7% of the households tend to serve the men of the households first, while 32.3% serve women and in 15.7% of the cases, they all eat at the same time (Fig. 4).

Figure 5 illustrates the dietary diversity of the households in the study area. Ninety-two percent of the households had high dietary diversity compared to 7 and 1% who had medium and low dietary diversity, at the time of conducting the study.

Figure 6 shows that most of the food groups were common in the study area. The household diets of those in the study area were dominated by cereals, dark green leafy

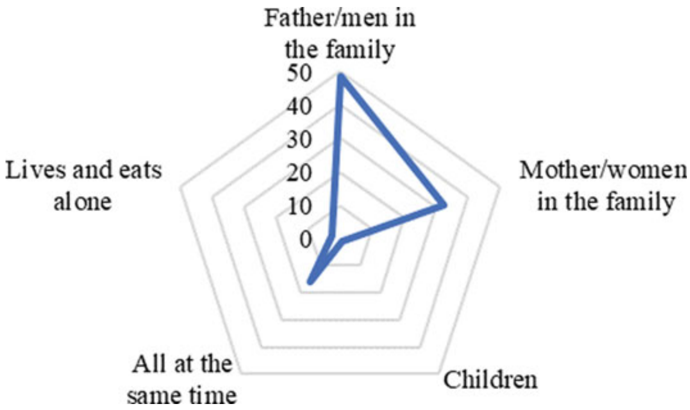

Fig. 4 First to eat in the household

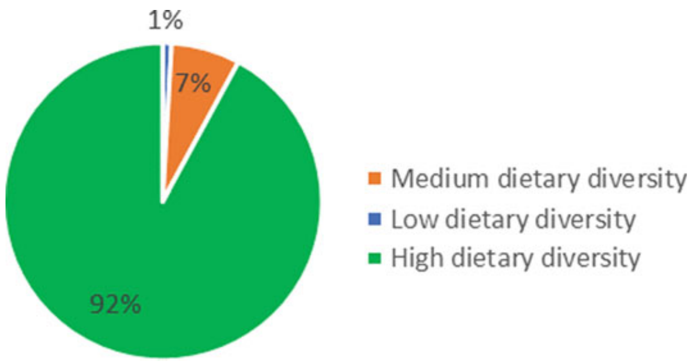

Fig. 5 Dietary diversity of households

vegetables, eggs, oils and fats, spices, condiments and beverages. Less utilisation was evident of white tubers and roots, fruits, as well as fish and sea foods.

Table 3 shows the intra-household cooking responsibilities for the various household members given their purchase of different types of food. Male heads were responsible for cooking in households that purchased white tubers and roots (21.9%), legumes, nuts and seeds (18.4%) and leafy vegetables (18.3%). On the other hand, female heads and wives had more cooking roles in households that purchased food across the board. Female heads responsible for cooking preferred to purchase fruits, milk and dairy, and sweets, respectively. Households whose wives were responsible for cooking preferred to purchase fruits and meat, respectively.

Table 4 depicts the cooking role players given the production of food. In households were male heads were responsible for cooking, they preferred meat and white tuber production, respectively. Households with a female head as the cook preferred producing cereals, white tubers and meat, respectively.

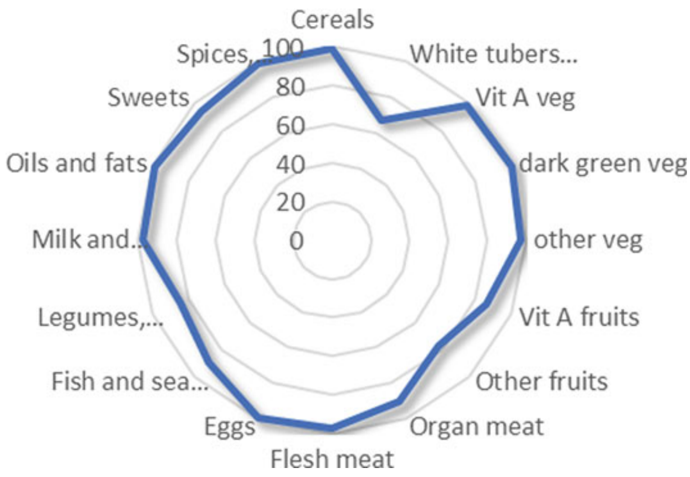

Fig. 6 Food that is common in the study area

Relative to cooking roles, husbands were more involved in food buying in households that purchased food. This was, however, still overshadowed by female heads across the various foods. Table 5 indicates that in households that purchased food, female heads and male heads as well as husbands opted to purchase vegetables and white tubers and roots. Wives with food purchase responsibilities opted for fruits, sweets and meat, respectively.

Table 6 shows that male heads dominated the production of food given their food buying roles. Male heads with food buying responsibilities preferred to produce cereals and meat, whereas female heads were inclined to use legumes and fruits.

Female heads dominated household members that do home gardening when given the responsibility to purchase the various types of food (Table 7). Relative to female heads responsible for home gardening and opting to purchase vegetables and sweets, male heads were inclined to purchase tubers, fruits, fish and legumes, respectively.

In households producing their own food, all the males preferred producing cereals, while 66.7% and 50% preferred producing tubers and meat, respectively (Table 8). Half of the female heads responsible for home gardening preferred producing legumes and spices, while 55.6% of the husbands who were responsible for home-garden preferred producing milk and milk products.

The chi-square results of all tables indicated insignificant associations between the variables. The results therefore failed to reject the null hypothesis of no association between role-playing and food utilisation, and thus indicate that there is no association between role-playing and food utilisation.

Table 3 Household food cooking roles and purchase of various foodstuffs (%)

Household role	Cereals	White tubers and roots	Vitamin A vegetables	Leafy vegetables	Other vegetables	Vitamin A fruits	Other fruits	Organ meat	Flesh meat	Eggs	Fish and sea food	Legumes, nuts and seeds	Milk and dairy products	Oils and fats	Sweets	Spices, condiments and beverages
Male head	17.1	21.9	16.1	18.3	16.7	14.4	14.3	16.0	15.8	17.2	16.3	18.4	16.5	16.2	16.7	16.1
Husband	6.3	3.1	8.0	2.8	6.0	6.7	6.5	6.0	6.9	7.1	7.2	6.9	6.8	6.3	5.9	6.3
Female head	36.0	32.8	36.8	36.6	33.3	35.6	39.0	36.0	33.7	37.4	36.1	34.5	38.8	36.9	38.2	37.5
Wife	22.5	20.3	20.7	21.1	22.6	24.4	20.8	23.0	23.8	19.2	21.6	20.7	19.4	22.5	21.6	22.3
Married daughter or daughter-in-law	1.8	1.6	–	–	–	2.2	1.3	2.0	2.0	2.0	2.1	2.3	1.0	1.8	2.0	1.8
Young teen mother	0.9	1.6	–	–	1.2	1.1		1.0	1.0	1.0	1.0	1.1	1.0	0.9	1.0	0.9
Girl child	3.6	4.7	4.6	5.6	4.8	4.4	5.2	4.0	4.0	3.0	4.1	4.6	3.9	3.6	3.9	3.6
Yourself	9.0	10.9	10.3	12.7	11.9	7.8	10.4	9.0	9.9	10.1	8.2	8.0	9.7	9.0	7.8	8.9
Any other person	2.7	3.1	3.4	2.8	3.6	3.3	2.6	3.0	3.0	3.0	3.1	3.4	2.9	2.7	2.9	2.7

Table 4 Household food cooking roles and production of various foodstuffs (%)

Household role	Cereals	White tubers and roots	Vitamin A vegetables	Leafy vegetables	Other vegetables	Vitamin A fruits	Other fruits	Organ meat	Flesh meat	Eggs	Fish and sea food	Legumes, nuts and seeds	Milk and dairy products	Oils and fats	Sweets	Spices, condiments and beverages
Male head	–	33.3	19.4	15.1	13.5	25.0	–	50.0	9.1	7.1	15.9	–	–	–	–	–
Husband	–	–	–	9.4	5.4	–	25.0	–	–	–	6.2	–	–	–	–	–
Female head	100	55.6	41.9	35.8	45.9	50.0	50.0	–	54.5	35.7	37.2	57.1	11.1	–	–	50.0
Wife	–	–	22.6	24.5	24.3	25.0	–	–	9.1	42.9	23.0	42.9	66.7	–	–	50.0
Married daughter or daughter-in-law	–	11.1	6.5	3.8	2.7	–	–	–	–	–	1.8	–	–	–	–	–
Young teen mother	–	–	3.2	1.9	–	–	25.0	–	–	–	0.9	–	–	–	–	–
Girl child	–	–	3.2	1.9	2.7	–	–	50.0	27.3	14.3	3.5	–	11.1	–	–	–
Yourself	–	–	3.2	3.8	2.7	–	–	–	–	–	8.8	–	11.1	–	–	–
Any other person	–	–	–	3.8	2.7	–	–	–	–	–	2.7	–	–	–	–	–

Table 5 Household food buying roles and purchase of various foodstuffs (%)

Household role	Cereals	White tubers and roots	Vitamin A vegetables	Leafy vegetables	Other vegetables	Vitamin A fruits	Other fruits	Organ meat	Flesh meat	Eggs	Fish and sea food	Legumes, nuts and seeds	Milk and dairy products	Oils and fats	Sweets	Spices, condiments and beverages
Male head	20.7	25.0	16.1	16.9	16.5	21.1	23.1	21.0	18.8	21.2	22.7	23.0	21.4	21.6	20.6	21.4
Husband	14.4	15.6	16.1	14.1	15.3	13.3	9.0	14.0	14.9	13.1	14.4	13.8	12.6	14.4	12.7	14.3
Female head	39.6	40.6	43.7	43.7	42.4	37.8	41.0	39.0	39.6	39.4	40.2	36.8	41.7	38.7	40.2	39.3
Wife	14.4	9.4	11.5	9.9	12.9	16.7	14.1	15.0	14.9	14.1	13.4	14.9	12.6	14.4	15.7	14.3
Married daughter or daughter-in-law	1.8	3.1	2.3	1.4	1.2	2.2	2.6	2.0	2.0	2.0	1.0	2.3	1.9	1.8	2.0	1.8
Young teen mother	0.9	–	1.1	1.4	1.2	1.1	1.3	1.0	1.0	1.0	1.0	1.1	1.0	0.9	1.0	0.9
Girl child	0.9	–	1.1	1.4	1.2	1.1	–	1.0	1.0	1.0	1.0	1.1	1.0	0.9	1.0	0.9
Yourself	6.3	6.3	6.9	9.9	8.2	5.6	7.7	6.0	6.9	7.1	5.2	5.7	6.8	6.3	5.9	6.3
Any other person	0.9	–	1.1	1.4	1.2	1.1	1.3	1.0	1.0	1.0	1.0	1.1	1.0	0.9	1.0	0.9

Table 6 Household food buying roles and production of various foodstuffs (%)

Household role	Cereals	White tubers and roots	Vitamin A vegetables	Leafy vegetables	Other vegetables	Vitamin A fruits	Other fruits	Organ meat	Flesh meat	Eggs	Fish and sea food	Legumes, nuts and seeds	Milk and dairy products	Oils and fats	Sweets	Spices, condiments and beverages
Male head	66.7	33.3	32.3	24.5	25.0	25.0	–	50	45.5	21.4	21.2	14.3	11.1	–	–	–
Husband	–	11.1	9.7	15.1	13.9	25.0	–	–	9.1	21.4	14.2	–	33.3	–	–	–
Female head	–	44.4	22.6	34.0	27.8	25.0	50.0	50	27.3	35.7	39.8	57.1	33.3	–	–	50
Wife	–	11.1	19.4	18.9	13.9	25.0	50.0	–	9.1	14.3	14.2	28.6	–	–	–	50
Married daughter or daughter-in-law	33.3	–	3.2	1.9	5.6	–	–	–	–	–	1.8	–	–	–	–	–
Young teen mother	–	–	–	–	–	–	–	–	–	–	0.9	–	–	–	–	–
Girl child	–	–	–	–	–	–	–	–	–	–	0.9	–	–	–	–	–
Yourself	–	–	12.9	3.8	11.1	–	–	–	9.1	14.3	6.2	–	22.2	–	–	–
Any other person	–	–	–	1.9	2.8	–	–	–	–	–	0.9	–	–	–	–	–

Table 7 Household food garden roles and purchase of various foodstuffs (%)

Household role	Cereals	White tubers and roots	Vitamin A vegetables	Leafy vegetables	Other vegetables	Vitamin A fruits	Other fruits	Organ meat	Flesh meat	Eggs	Fish and sea food	Legumes, nuts and seeds	Milk and dairy products	Oils and fats	Sweets	Spices, condiments and beverages
Male head	20.4	25.0	16.7	17.1	14.6	18.4	22.7	20.6	18.4	21.9	22.3	22.4	22.0	21.3	20.2	22.0
Husband	17.6	14.1	17.9	12.9	19.5	18.4	14.7	17.5	18.4	15.6	18.1	18.8	14.0	17.6	16.2	17.4
Female head	30.6	28.1	31.0	32.9	31.7	31.0	29.3	30.9	30.6	31.3	28.7	25.9	32.0	30.6	32.3	30.3
Wife	4.6	4.7	3.6	5.7	4.9	5.7	4.0	5.2	5.1	4.2	4.3	3.5	5.0	4.6	5.1	4.6
Young teen mother	2.8	4.7	3.6	2.9	3.7	3.4	4.0	3.1	3.1	3.1	3.2	2.4	3.0	2.8	3.0	2.8
Girl child	1.9	1.6	2.4	1.4	2.4	2.3	2.7	2.1	2.0	2.1	2.1	2.4	2.0	1.9	2.0	1.8
Yourself	14.8	15.6	15.5	18.6	15.9	13.8	17.3	14.4	15.3	14.6	14.9	15.3	14.0	13.9	13.1	13.8
Any other person	7.4	6.3	9.5	8.6	7.3	6.9	5.3	6.2	7.1	7.3	6.4	9.4	8.0	7.4	8.1	7.3

Table 8 Household food garden roles and production of various foodstuffs (%)

Household role	Cereals	White tubers and roots	Vitamin A vegetables	Leafy vegetables	Other vegetables	Vitamin A fruits	Other fruits	Organ meat	Flesh meat	Eggs	Fish and sea food	Legumes, nuts and seeds	Milk and dairy products	Oils and fats	Sweets	Spices, condiments and beverages
Male head	100	66.7	36.7	29.4	32.4	25.0	25.0	50.0	45.5	21.4	21.8	16.7	11.1	–	–	–
Husband	–	–	13.3	21.6	14.7	25.0	25.0	–	9.1	28.6	17.3	16.7	55.6	–	–	–
Female head	–	11.1	23.3	21.6	23.5	25.0	25.0	–	18.2	21.4	30.0	50.0	–	–	–	50.0
Wife	–	–	6.7	3.9	2.9	–	–	–	–	7.1	4.5	–	11.1	–	–	50.0
Young teen mother	–	–	–	2.0	–	–	–	–	–	–	2.7	–	–	–	–	–
Girl child	–	–	3.3	2.0	2.9	–	–	–	–	–	1.8	–	–	–	–	–
Yourself	–	11.1	13.3	11.8	11.8	–	25.0	50	18.2	14.3	14.5	–	22.2	–	–	–
Any other person	–	11.1	3.3	7.8	11.8	25.0	–	–	9.1	7.1	7.3	16.7	–	–	–	–

4 Discussion

At the time of conducting the study, most of the respondents had acquired Grade 12 education and thus can read and write. Mutisya et al. (2016) indicated that educational levels have an inverse relationship with food insecurity. Furthermore, a high educational level means a higher probability of improving income through formal employment as well as the ability to comprehend food production techniques (Raidimi and Kabiti 2019).

There were more male children, with their averages being less for male youths and adults, compared to females. This is typical of South African rural setups where the number of male youths and adult decreases due to migration in search of better working opportunities in bigger towns and cities. This has a bearing on the labour supply that negatively affects food production (Baiphethi and Jacobs 2009; Musemwa et al. 2013; Mikalitsa 2015; Cheteni et al. 2020).

Eighty-one percent of the respondents had been living in the study area for more than 15 years. The duration of stay makes the respondents acclimatised to climate and weather conditions within the area. They have extensive knowledge of their food sources, whether it be from purchasing or from own production. In terms of own food production, the respondents have an aptitude in the crops and vegetables that can be sustainably produced to meet their needs. Mutisya et al. (2016) acknowledge that duration of stay is a coping strategy whereby a long stay establishes networks to face food insecurity challenges.

The study found that males were served food first in the households, followed by women. Henry-Unaeze et al. (2012) found that due to this cultural norm, the largest quantity of food tends to be consumed by fathers, mothers, youngest child, oldest child, and the rest, respectively. This improper food allocation thus has a malnutrition burden. D'souza and Tandon (2015) also found that male heads were adequately nourished compared to women and children. This was confirmed by KIT et al. (2017) who highlighted that males often have larger shares of meat as a sign of respect from their wives, and this would reinforce males buying more meat for the household.

There was high dietary diversity in the study area. The findings concur with Musemwa et al. (2018) who found that 61% of households in Nkonkobe (now Raymond Mhlaba) Local Municipality had a high dietary diversity. Ngema et al. (2018) also found high dietary diversity in South Africa. This was contrary to Taruvinga et al. (2013) who found that there was an even distribution of households with high, medium and low dietary diversity, in Amatole District Municipality, where the study area is located. Furthermore, household diets are dominated by cereals, dark green leafy vegetables, eggs, oils and fats as well as spices, condiments and beverages. There is less utilisation of white tubers and roots, fruits, as well as fish and sea foods. This was also contrary to Taruvinga et al. (2013) who highlighted very low levels of milk, vegetables, fruits, eggs and fish within Amatole District Municipality. Ngema et al. (2018) indicated high consumption of maize, beans, rice and oils, respectively. Cheteni et al. (2020) further found low dietary diversity in the

Eastern Cape Province of South Africa, with households mainly concentrating on milk, cereals and pulses. Musemwa et al. (2018) discovered that between households that practise farming and those that do not, there were significant differences in their diets concerning legumes, with no differences in the other types of foods. These results indicate contextualisation in terms of dietary diversity, being inherent on the particular circumstances of the households.

Female heads were responsible for buying and cooking food, as well as home gardening. Henry-Unaeze et al. (2012) reported that most food procurement was through home grown foodstuffs, with individual food distribution of mainly roots, tubers, legumes and cereals, as well as fruits and vegetables. The food distribution of female head and male head, according to Henry-Unaeze et al. (2012), does not favour children, as food choices are pre-determined.

Male heads responsible for cooking preferred purchasing tubers, legumes and leafy vegetables. Female heads preferred fruits, milk and sweets. According to Taruvinga et al. (2013), due to the fact that women are involved in food preparation, food selection will be influenced by women's knowledge regarding nutritional benefits. Kusago and Barham (2001) highlighted that males had considerable financial decision-making power, mostly reflective of patriarchal societies. However, the study identified that there was no difference between male- or female-based decisions in terms of market purchase. The study however did identify significant differences in the food purchase preferences between males and females in the same household. Male heads responsible for cooking preferred meat and tubers production, whilst female heads preferred cereals, tubers and meat.

Female heads preferred to purchase vegetables, tubers and roots when they were responsible for food purchase. This was contrary to the HSRC (2010) finding of female-headed households in the Eastern Cape Province of South Africa having lower food expenditures than male-headed households. The report identified female-headed households spending between 53 and 65% of their total household expenditure on food. This was due to their high poverty levels, where a larger share of income is spent on food. Mikalitsa (2015) supports that in order to enhance household nutrition, especially for children, there is need to enhance household resource allocation amongst women. Van den Broeck et al. (2021) highlighted that intra-household effects (responsibilities) may determine food expenditure. A higher preference towards nutritious foods amongst women leads to increased food expenditure. Aromolaran (2009), however, found that intra-household expenditure responsibilities did not affect calorie intake.

Various role players involved with food purchase responsibilities within the households purchased a variety of foods which included vegetables, tubers, roots, fruits and meat. HSRC (2010) found that in South Africa, rural households preferred bulk buying of cereal-grain staples, processed foods, fruits and vegetables. Furthermore, female-headed households spend less on fruit and vegetables.

Male heads were more involved in the production of food if they were responsible for buying food. They preferred to produce items like cereals and meat, whereas female heads preferred to produce legumes and fruits. More female heads carried out home gardening when they were responsible for food purchase. They preferred to purchase vegetables and sweets, whereas males with home-garden responsibilities preferred to purchase tubers, fruits, fish and legumes. According to Musemwa et al. (2018), there is significantly higher dietary diversity for households practising integrated farming than for those that are not. However, home gardening is viewed as a supplementary rather than main food source. Furthermore, women are generally more involved in home gardening (Ferdous et al. 2016).

All males who were responsible for home gardening in households producing their food preferred cereals, tubers, meat and milk. Female heads preferred legumes and spices. KIT et al. (2017) affirm that home gardens have empowered women in household decision making, especially concerning diet. The study however confirmed male controlled animal consumption decisions, whereas females were responsible for vegetables. Furthermore, males were more responsible for home-garden products that were market destined (KIT et al. 2017). Adekunle (2013) found that in Nkonkobe, Eastern Cape Province, spinach was the most produced vegetable in home gardens, followed by potatoes, cabbages, onion and tomato, respectively. The majority of the respondents in the study were dependent on their own production. Selepe and Hendriks (2014) found that in KwaZulu-Natal Province, South Africa, home gardens increased dietary diversity and improved nutrient intake. Cabalda et al. (2011) acknowledge that home gardening is a sustainable strategy in dietary diversity. Home gardens are complementary food sources but they are the form of food access closest to households. They support households against the negative effects of food price hikes and the destructive impact of agricultural technologies on the environment. Furthermore, there is continuous production throughout the year, and the proximity to households and kitchens means they contribute significantly to food utilisation (Adeosun et al. 2020). Home gardening improves the status of women in the households (Amenu 2017). KIT et al. (2017) did, however, acknowledge that there were variations in the gardening responsibilities within households, with males responsible for setting up the garden, whilst management and maintenance were left for the other family members to deal with.

In terms of home gardening activities, Khanal and Khanal (2017) indicated that males in the households were more inclined to activities such as digging holes, pruning and planting. Women were more likely to be involved in fencing, weeding, fertilising and watering. Furthermore, women spend most of their time in pre-harvesting activities. The study further found that women were involved in all aspects of the home garden, from land selection to crop or vegetables selection and harvesting. Both men and women were involved in mulching as well as application of ash as pest control.

However, even though relationships were observed between the various roles played in the household and food utilisation, no association was established. In this instance, the hypothesis of a relationship between role-playing and food utilisation was not confirmed.

5 Conclusion

Intra-household data contributes to identifying undernourished populations, especially women and children. The results indicate a complex relationship between socio-economic responsibilities in the household such as cooking, food buying and home gardening and status in the home (Table 9). However, there was no association between role-playing and food utilisation. Thus, the hypothesis of a relationship between household role-playing and food utilisation was rejected.

Table 9 shows that if the male head has the purchasing role, whether they are responsible for cooking, purchasing or home gardening, they prefer tubers and roots as well as legumes. Male heads that have a food production role, regardless of the responsibility of cooking, purchasing food or home gardening, prefer meat. Female heads have different preferences based on their purchasing and/or producing role and their cooking, purchasing and home gardening responsibilities. The foodstuffs that are common, regarding the various roles and responsibilities of the male and female heads in the households, include tubers and roots, fruits, meat, legumes and vegetables, respectively. From the study, it can be concluded that female heads are the nutritional gatekeepers and moderators in the households. Improving women's home-garden management activities will go a long way in benefiting the households not only through a diversified diet, but also benefitting the environment through sustainable practices.

Table 9 Summary of foods based on roles and responsibilities

Responsibility	Role			
	Purchasing		Producing	
	Male head	Female head	Male head	Female head
Cooking	1. Tubers and roots 2. Legumes 3. Vegetables	1. Fruits 2. Milk and dairy 3. Sweets	1. Meat 2. Tubers and roots 3. Fruit	1. Cereals 2. Tubers and roots 3. Meat
Purchasing	1. Tubers and roots 2. Legumes 3. Fish and sea food	1. Vegetables 2. Fruits 3. Fish and sea food	1. Cereals 2. Meat 3. Vegetables	1. Legume 2. Meat 3. Fruits
Home-garden	1. Tubers and roots 2. Fruits 3. Legumes	1. Vegetables 2. Sweets 3. Milk and dairy	1. Cereals 2. Tuber and roots 3. Meat	1. Legumes 2. Spices 3. Fruits

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Indigenous *Pokkali* Farming in Kerala: A Sustainable Social-Ecological Model

Aswathy Mohan and Chitra Karunakaran Prasanna

1 Introduction

Indigenous Farming Systems (IFS) were developed by local communities in diverse agro-ecological and socio-cultural habitats towards ensuring food security and livelihood stability (FAO 2009). Amidst the growing commercialization in agriculture, indigenous farming practices have survived filling rural landscapes with diversified agrarian systems. In developing countries, 10–15% of the cultivated land is occupied by indigenous farming systems which contributes to 30–50% of domestic food production. Unique farming knowledge and practices are created by the indigenous farmers which are instrumental in adapting the cultivation methods according to the attributes of the local environment. This stands in opposition to modern mono-cultivation systems with unscientific land use and unwise application of agrochemicals resulting in degradation of the natural eco-systems. Indigenous agricultural systems can help the ecology cope with anthropogenic threats with ecologically sound as well as financially viable farming practices which contribute to agricultural productivity and sustainability (Mohan et al. 2021).

India's states have developed a varied spectrum of indigenous agriculture methods. Some of the foremost indigenous farming methods practiced in the Indian states of Arunachal Pradesh, Meghalaya, Tripura, and Sikkim are agri-aqua integrated farming, jhum, and bun farming, organic farming, terrace rice cultivation, and so on.

Giri et al. (2020) tree-based cultivation practices in central and southern Indian states such as Uttar Pradesh, West Bengal, and Karnataka, as well as animal husbandry, in Uttar Pradesh and Madhya Pradesh (Patel et al. 2020) are also examples

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of aboriginal agricultural methods in India. Wetland environment is the foundation of the majority of India's indigenous farming practices, particularly in Kerala.

Kerala, which falls in the southernmost part of the country is a coastal state with a shoreline of 580 km (Chandramohanan and Mohanan 2011). The state of Kerala has about 217 wetland areas, making up a significant percentage of the state's overall land area. With an extend of more than 20% of the state's total wetlands, the district of Ernakulam contains the largest area of wetlands, followed by the districts Alappuzha and Thrissur with 15.8% and 12.99% respectively.

The Vembanad–Kole, Ashtamudi, and Sasthamcotta lakes, which are classified in the Ramsar index, are among Kerala's wetlands of international and national significance with an area of more than 1500 km^2 and a capacity of 0.55 km^3, the Vembanad Wetlands are the state's largest aquatic body and, covers Alappuzha, Kottayam, Ernakulam, and Thrissur districts. This vast hydrological system is made up of coastal lakes, streams, reeds, and mangroves. Most of the indigenous agricultural systems of Kerala are located in proximity of these water bodies (Kokkal et al. 2008).

In Kerala, paddy growing using integrated farming techniques is a common practice (Vijayan 2016). The majority of Kerala's paddy is grown in coastal marshes and low-lying places like Kuttanad. Almost thirty-seven percent of the total rice produced in Kerala is from the low-lying paddy wetlands (Chandramohanan and Mohanan 2011). The littoral intertidal wetlands in Kerala fall among the world's most productive ecosystems and are known for their rich biodiversity (Shinogi et al. 2019). The method of indigenous paddy-shrimp integrated production exclusively found in the salinity-prone wetlands of Ernakulam, Alleppey, Thrissur, and Kannur districts are locally known as "*pokkali/ kaipad/ kaikandam* agriculture (Nambiar and Raveendran 2009). Eighty-four percent of the area under indigenous farming systems in Kerala is occupied with *pokkali* fields (Sudhan et al. 2016). These farming systems follow organic methods and hence need only very little external input. In natural field conditions, paddy/shrimp production is generally resistant to pests and diseases and ensures local livelihood and food security. The sustainability of this production system is ensured by the compatibility of various social and ecological factors, stable harvests, desirable soil bio-hydrological conditions, and economic benefits (Sasidharan et al. 2012).

2 Origin and History of *Pokkali* Farming in Kerala

Indigenous paddy and shrimp farming culture was largely practiced in Kerala, in a total area of 25,000 hectares (Shyna and Joseph 2000). *Pokkali* refers to an indigenous salt-resistant paddy variety cultivated in Kerala for the last 3000 years. Currently, it is a certified organic product. The term '*pokkali*' is a combination of two Malayalam words: "*pokkathil*', which means tall, and '*aali*', which implies plentiful growth (Sudhan et al. 2016). According to history, until the fourteenth century, this indigenous paddy type flourished exclusively in the peak areas of the Western Ghats in

Kerala's Idukki region. The paddy variety is said to have reached the districts of Thrissur, Ernakulam, and Alleppey during a large flood (Shaji 2021). Another narrative on *pokkali* paddy is that the Konkani-speaking *Kudumbi* community brought the grain with them when they relocated from Goa to Kerala. *Pokkali* is also grown in Sri Lanka which could have come to the island through Buddhist missionaries. The narratives surrounding *pokkali* are intertwined with the tales of migrations that happened in Kerala (A 2016). Gradually the rice has become a part of the State's heritage and tradition (Shinogi et al. 2019). The map depicting *pokkali* farming districts in Kerala is given in Fig. 1. The area coloured in blue on the map of India represents the physical location of Kerala state, whereas the areas shaded in yellow on the map of Kerala indicate the state's pokkali cultivating districts.

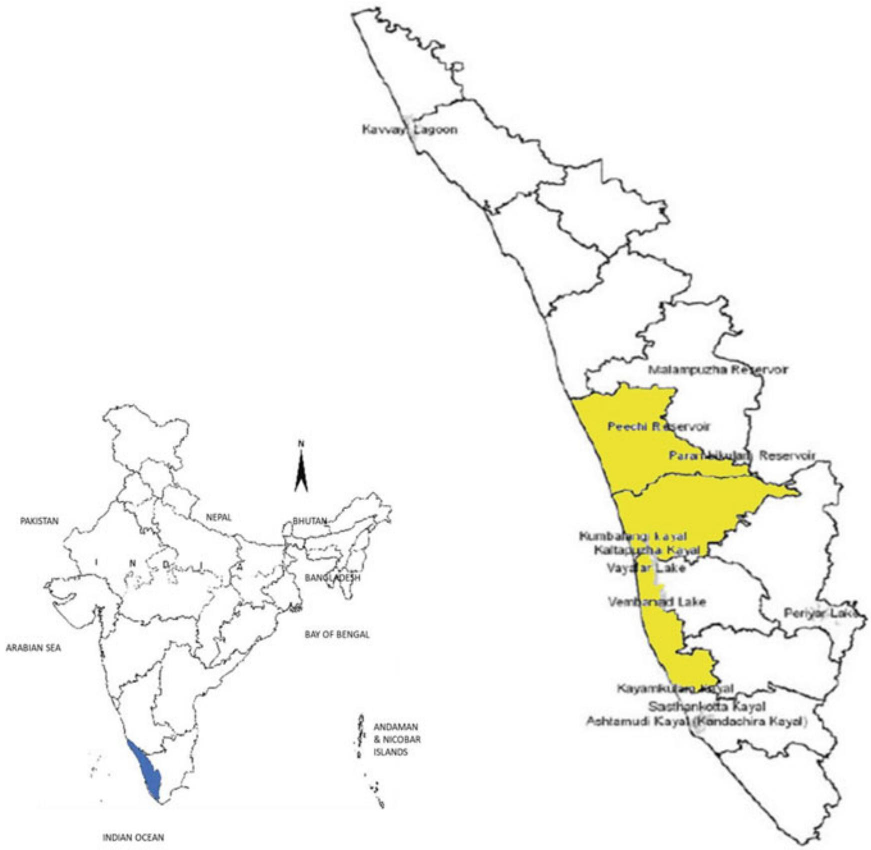

Fig. 1 *Pokkali* Cultivating Districts in Kerala (*Source* National Wetland Atlas: Kerala, Government of India 2010)

3 Social-Ecological System Dynamics in *Pokkali* Farming

Through integrating a number of social and ecological structures, the *pokkali* wetlands offer numerous services such as habitat provision, seed banks, and nutrient cycling as well as social and recreational opportunities such as farming, fishing, and cattle rearing.

Indigenous agroecosystems are often seen as an alternative route to sustainable rural development (Giraldo 2019) for which the *pokkali* system is a classic example. Though an ideal social-ecological model, *pokkali* farming system is undergoing massive changes in its social and ecological features due to paradigmatic shifts in development policies and practices concerning environmental governance. Wetlands across the globe, including indigenous farming systems like *pokkali,* are subjected to multiple stakeholder conflicts in terms of property ownership and access which may result in adverse consequences for both social and ecosystem health. Because wetland circumstances and social-ecological dynamics are frequently re-engineered to adapt for changes in both technology and societal preferences, wetland conditions and social-ecological dynamics change quickly and clearly (Taylor 2019). Wetlands are an ideal setting for studying the long-term reworking of society-nature relationships in a region. The conflicting power-relations in indigenous farming systems which engage multiple stakeholders is a reality that demands continuous monitoring and intervention mechanisms. Exploring *pokkali* wetlands through a political–ecological lens sheds light on the dynamics of environmental governance inherent in them, long-term effects of social and environmental shifts, and policy interventions on demand by the system.

4 *Pokkali* Farming Systems—Techniques and Strategies

Pokkali cultivation is a comprehensive agricultural practice that promotes the quality of agro-ecosystems, including soil activity and biological diversity. Instead of synthetic components, agronomic, biological, and mechanical approaches are used to satisfy any specific function inside the system. Techniques and strategies utilized to scientifically manage *pokkali* farming system are described in the following sections.

5 Agri-aqua Integration

Integrated agri-aqua farming is a multi-land use method in food production that incorporates shrimp/fish culture along with other agricultural production systems. The symbiotic nature of paddy and shrimp/fish cultivation is the crux of *pokkali* farming technique (Suchitra and Venugopal 2005; Sreelatha and Shylaraj 2017). *Pokkali* wetlands lie in coastal belt hence are vulnerable to consistent flooding and saline intrusion. This geographical peculiarity is used to facilitate cultivation practice in *pokkali* farming system. Different varieties of *pokkali* paddy used by native farmers include '*Chettivirippu*', '*Vyttila 1*', and '*Vyttila 2*' (Vijayan 2016). *Pokkali* paddy grows to a height of 4.5–6 feet and preserves its grains straight above the water level for nearly ten days during high tide or river flooding, while the plant itself bends over and falls (Manipadma 2017). During the low-saline phase, paddy cultivation is conducted in the *pokkali* tracts, which is substituted with shrimp farming during high-saline phase. Another key element of this farming method is the natural recycling of waste materials (Shaju et al. 2014). For example, the shrimps consume the biomass deposits of the rice crop and the excretion of the shrimp decompose and become the manure for paddy, thereby creating a symbiotic zero input and organic production system (Antony Kuriakose 2015).

Pokkali farming enhances land-use efficiency while reducing soil degradation. The soil of *pokkali* wetlands is clay-textured with a high water-holding capacity and acidity making the area generally unfit for paddy farming. The soil of *pokkali* wetlands are not suitable for rice cultivation since it is clay-textured with a high water-holding capacity and acidity. However, the *pokkali* variety, which is tolerant to salinity and flood water, is suitable for the properties of soil.

The unique attribute of this land is that it produces excellent yields in the absence of chemical pesticides or fertilizers (Ranjith et al. 2018). *Pokkali* paddy has adapted to resist soil acidity and submergence, making it ideal for climate-adaptive agriculture. *Pokkali* paddy's salt tolerance gene, SalTol QTL, could be significant to international rice improvement projects that focus on salinity tolerance. Paddy can also act as a natural biofiltration system, improving the water and soil quality, reducing the danger of disease outbreaks in shrimp or fish crops (30% less risk compared to mono-shrimp) (Shinogi et al. 2019). *Pokkali* lands are also used for cattle grazing, duck rearing, and as a habitat for several organisms (Antony 2017).

6 Water Management

The integrated paddy/shrimp farming system employed in *pokkali* field depends profoundly on proper water management. Since the fields are mostly below sea level, water is drawn by gravity flow from the neighboring canal system and used for irrigation (Suchitra and Venugopal 2005). To reduce risk of flash floods and preserve soil and agricultural health, '*thoompu*', or sluice gates, are used. After passing through a feeder canal, the saltwater arrives into the fields during cultivation. The sluice gate attached about thirty centimeters from the field area facilitates transport of water into the ground. In the course of high flows, water is pumped into the fields and then it is sieved across velon nets and split bamboo traps to remove the crop-destroying species such as fish, shrimp, and carnivores (Joy 2019). Another sluice opening is operated during low tides to divert water from the culture area to the feeder channel for exchange, desalination, and discharge of water. Wooden shutters are installed on the sluice gate's entry and exit mouths to control the water flow (Shyna and Joseph

2000). The *Thanneermukkom* saltwater barrier also keeps brackish water out, making paddy cultivation easier in the post-monsoon season. The fields are permitted to have a free exchange of water throughout the transient period (Shaju et al. 2014).

7 Organic Weed and Pest Management

Since *pokkali* cultivation is a type of organic agriculture, the fields are home to a variety of aquatic and semi-aquatic pests and weeds (Sreelatha and Shylaraj 2017). Three pests *Thanduthurappanpuzhu (Scirpophaga incertulas), Chazhi (Mupli beetle),* and *Ela churuttipuzhu (Cnaphalocrocis medinalis)* cause around 20 to 25% damage to the crops (Joy 2019). Paddy cultivation in *pokkali* fields is hampered by weeds also. Fourteen aquatic weed species were discovered in *pokkali* fields (Deepa 2014) in which the floating migratory weeds such as water hyacinth *(Eichornia crassippes),* water moss *(Salvinia auriculata),* and more recently, duckweeds *(Lemna minor)* cause severe disturbance to *pokkali* cultivation. Unwanted plants and weeds are removed either before or after the seedlings are transplanted. Weed removal is performed only once during the cultivation process, and it is mostly done by female labourers (Vijayan 2016). Weed control is also accomplished by raising water levels and allowing free flow of brackish water into and out of the field. These weeds, as well as the flora and fauna, decay and contribute to soil fertility during high salinity phase. A non-native seasonal bird known as *Nelli kozhi (Purple moorhen*) seen in *pokkali* fields from January to September, causes crop damage to *pokkali* fields (Sreelatha and Shylaraj 2017). Long strings attached to empty polyethylene bags are kept around the field to keep birds away (Joy 2019). These bags flutter in wind, making a noise that scares away birds. Bird scares are also used to keep the crop safe from predators. However, since the pest and disease occurrence in these fields is below the threshold level, only a small amount of organic manuring or plant defense is used. Chemicals are not used in these fields due to the potential harm they can cause to paddy and shrimp (Antony 2015). The low frequency of pests and illnesses can also be attributed to the presence of natural enemies and predators.

8 Application of Indigenous Knowledge

The indigenous wisdom associated with *pokkali* cultivation contributes significantly to the food security and ecological protection of agro zones. The soil classification system adopted by *pokkali* farmers contributes to the prevention of soil erosion and improvement of land quality and nutrient recycling in *pokkali* fields. This method has evolved from the indigenous knowledge base of the local farmers. The indigenous method of regulating flow of water via sluice gates helps for effective water management in the *pokkali* tracts. The efficient management of natural resources and planned allocation of skilled human labour in the *pokkali* fields lead to local environmental conservation and rural poverty alleviation (Manipadma 2017). In the long run, the application of the indigenous knowledge base of the community in the agricultural systems results in climate change mitigation and control of natural disasters (Joshy 2018).

9 Institutional Management in *Pokkali* Cultivation

The Department of Agriculture of the Government of Kerala had launched the *padasekharam* (polder) strategy in the 1980s, to improve paddy output through joint administration of farming methods and community participation. '*Padashekharam*' refers to the collection of several small fields into a viable field, to conduct farming. Dewatering, bund construction, and decision-making are all carried out in each *Padasekharam* based on the direction of a *Padasekharam committee* comprising the farmers. Farmers, on the other hand, are responsible for the actual planting here (Srinath et al. 2000). The cost-effective use of agricultural machinery for tillage, transplanting, harvesting, and threshing is made possible by the community farming system of cultivation used in *pokkali* lands. The fields, on the other hand, are almost always susceptible to flooding. As a result, indigenous pumps are used to dewater the fields into nearby water canals (Joy 2019). Each "*Paadasekharam*" has one to six similar pumps to handle the levels of water throughout the cultivation process.

Soon after the paddy harvest, the grounds will be given to the shrimp growers for a five-month period between November and mid-April. To get a license for shrimp cultivation, the people have to register with the Kerala Government's Department of Fisheries. The tenure of the lease depends upon the productivity of the fields, location, and vicinity of the water sources. The head of the group who brings agricultural labourers for farming practice takes the shrimp or fish caught in the sluice gate, as labour fee. Throughout this six-month period, the aquaculture is conducted on a profitmaking motive and the labors have the right to catch fish at the termination of the tenure period only (Antony 2015).

The government provides many assistance programs for *pokkali* farmers. Since the cultivation of *pokkali* is fully reliant on monsoons and tidal fluctuations, changes in rainfall and climatic conditions would have an impact on the crop, and a bad monsoon will result in crop failure. In these circumstances, the government provides subsidies, crop failure compensation, *etc.* for supporting the farmers. The "*Pokkali* Land Development Agency (PLDA)" was established by the government in 1996 to promote paddy farming in *pokkali* wetlands. To encourage community engagement, the local government, in partnership with "*Pokkali* Land Development Authority (PLDA)", is designing plans to promote the traditional, organic form of paddy production in the district. The Central Marine Fisheries Research Institute's "*Krishi Vigyan Kendra*" (Ernakulam) has introduced machinery appropriate for *pokkali* wetlands and provides training to women through a partnership with *Kudumbashree* programme (ibid). Cooperative societies serve the agricultural and allied sectors in the most productive way possible by offering sufficient, low-cost, and timely inputs and credit (Joy

2019). Under the name of "pokkali Samrakshana Samithi," a group of farmers and activists from Ernakulam and Alappuzha districts have banded together to rehabilitate pokkali farming lands. The PSS takes uncultivated *pokkali* lands for lease and conducts farming by making finance through informal '*pokkali* bonds' (Antony 2015).

10 The Social Relevance of *Pokkali* Farming

Wetlands are referred to as "biological supermarkets" on occasion. Wetlands provide a variety of benefits to society, including rural livelihood, food security, water security, and recreational activities. The different societal values of the *pokkali* farming system are listed below.

11 Rural Livelihood

The *pokkali* wetlands in Kerala act as a direct and indirect source of livelihood for the local community. Farming, fishing, tourism, coir retting, shrimp/ crab farming, and cattle fodder collection are major livelihood activities related to *pokkali* wetlands (Ranga 2006). The method of alternate harvesting paddy and shrimp provides farmers with consistent labour and money throughout the year. *Pokkali* farming requires 207 human labour-days per hectare, with 84 men and 123 women contributing to the labour force. Seasonal labour requirements for shrimp farming are projected to be 246 per hectare, with 181 men and 65 women forming the labour force (Shyna and Joseph 2000). Since women with traditional farming skills are the primary agricultural labourers in *pokkali* fields, the farming method promotes women's empowerment in the area by allowing them to be financially self-sufficient (Antony 2017). The tourist industry is recent to this area, but it has provided job possibilities for residents and also acts as a significant source of money for the state (Rajan et al. 2008).

12 Food Security

Pokkali cultivation is both a concept and farming practice aimed at producing food that is healthy and free of contaminants that could affect human health. *Pokkali* farms are the principal source of nutrition available to the native communities. The unique pattern of production ensures availability of *pokkali* rice and fish for the natives (Antony 2017). The '*kanji*' (rice gruel) prepared from *pokkali* rice is quite popular among the residents of this region. *Pokkali* rice is well-known for its flavour and is found in rice flour, rice bran, rice flakes, and a variety of local breakfast items. In a study conducted at the Rice Research Station in Ernakulam, the medicinal potential of pokkali rice was scientifically verified. The study discovered that antioxidants including, tocopherol, oryzanol, and tocotrienol are abundant in pokkali types (Sreelatha and Shylaraj 2017). These levels are significantly greater than those seen in *njavara,* a popular variety of medicinal rice available in Kerala. Since *pokkali* rice is high in amylase, it is suitable for diabetic patients too.

The availability of fish/shrimp varieties from the *pokkali* fields provides the local community with sufficient food sources as well as a variety of by-products. Naran (Penaeus indicus) and kara chemmen (Penaeus monodon), poovalan or thelly (Metapenaeus dobsoni), and choodan (Metapenaeus monocero) are among the overpriced shrimp species found in these fields. (Ranga 2006). The main fish varieties found in *pokkali* wetlands are *kolaan (Hyporhamphus limbatus), manja para (Caranx carangus), mangrove jack (Lutjanus argentimaculatus), nachara (Scatophagus argus), kanambu (Mugil cephalus),* and *milkfish (Chanos chanos)* (Deepa 2014). In the same land, several *pokkali* farmers grow tiger shrimp and crabs alongside native shrimp types (Ranjith et al. 2018), all of which contribute to the local food security in the region.

13 The Economic Value of *Pokkali* Cultivation

The pokkali farming system contributes significantly to the local and national economies by generating resources, promoting recreational opportunities, and providing services including pollution prevention and control and flood mitigation. Integrated paddy-shrimp farming is a highly cost-effective technique in farming. According to the studies, the net return for *pokkali* paddy farming alone is Rs. 62,864 (712 €) per hectare. However, it is compensated by farming shrimp in the following season, which yields a net return of roughly Rs. 343,879 (3782€) for one hectare of shrimp. The overall cost of cultivation for the complete production process is Rs. 239,505 (2634€), with a gross profit of Rs. 520,521 (5725€) (Karunakaran et al. 2019). Another study conducted in the Eranakulam district in 2019 found that the rotational production of *pokkali* rice-shrimp generates a net income of Rs 5.21 lakhs (5889.40 €) per year. Though paddy causes a loss of around Rs. 63,000 (712.15€) in this system, it is counterbalanced by Shrimp culture. Subsequently, the integrated cultivation generates a gross return of 2.81 (3176.43€) lakhs per year with an input–output ratio of 2.17, signifying that for every rupee invested in the system, a gross return of Rs. 1.17 could be reached, indicating the system's economic possibilities (Ranjith et al. 2018).

In addition, indigenous paddy-shrimp farming generated 20% more net revenue than conventional paddy production. On a larger scale, intensive management with time-bound care could increase the profit from the system. The *pokkali* paddy varieties VTL-3, VTL-4, and VTL-5 have been discovered to have a yield potential of 3500–4000 kg /Ha (Joy 2019), resulting in a greater economic output. Being a 100% organic product, there is plenty of room in the national and worldwide markets for *pokkali* rice and other value-added products. *Pokkali* rice is processed into value-added products, such as rice powder, which is utilized in a variety of regional dishes. The *pokkali* rice and shrimp have significant export opportunities in global markets, which could lead to a higher income generation (Srinath et al. 2000). The *pokkali* farming model is beneficial to tourism business as well (Priyadershini 2020). The Blue Yonder, for example, is a socially responsible tourism programme that collaborates with local farmers to promote *pokkali* regions as tourist destinations for those interested in learning about the unique agriculture, thereby providing a substantial source of revenue (Shaji 2021).

14 Ecological Relevance of *Pokkali* Fields

Pokkali wetlands belongs to the *Kole* wetlands of vembanad lake, India's major tropical estuary, which has been designated as a Ramsar site. *Pokkali* wetlands are multi-functional habitats that sustain a diverse range of biodiversity and hydrology. The key ecological services provided by *pokkali* farming system are detailed in the following paragraphs.

15 Water Security and Flood Control

The pokkali wetlands ensures water security across the coastal districts of Central Kerala (Shaji 2021). Indigenous *pokkali* farmers have created numerous water gathering structures and sources to ensure water availability in the tracts and domestic uses. Further, *pokkali* wetlands are surrounded by freshwater sources like Periyar, Muvattupuzha river, and Chalakudy rivers and backwater bodies like Kodungallor *Kaya*l, Varapuzha *Kayal,* and Vembanad *Kayal.* All through the monsoon season, these rivers overflow, causing severe flooding in low-lying regions along the banks (Antony 2015). By retaining a considerable amount of water, *pokkali* wetlands prevent flooding and waterlogging. Similarly, during storms and when water levels are high, these fields hold water which they slowly discharge when the water table is low. In this sense, *pokkali* wetlands prevent flooding/waterlogging and have an impact on ground-surface water recharge and discharge (Rajan et al. 2008).

Pokkali swamps also operate as water filters, boosting the quality of water in neighbouring water sources. When water enters a marsh, it decelerates and circumnavigates the vegetation (Joy 2019). Surplus micronutrients inside the water from fertilizers, manures, and urban liquid and solid sewage which can cause algal growth and pose a threat to aquatic life, are absorbed by plant body and organisms that lives on stems and leaves, as well as the soil in fields (Abraham 2004). Cropping in *pokkali* fields is also important because it allows precipitation to penetrate the subsoil (Priyadershini 2020). The proximity of several freshwater sources also lowers the salinity level in *pokkali* fields.

16 Biodiversity

The pokkali wetlands contribute to biodiversity preservation by sustaining a high concentration of aquatic wildlife, primates, various bird populations, amphibians and several other small organisms. Because of the changing characteristics of water, these fields offer a viable environment with a diverse range of organisms. The *pokkali* wetland region preserves a total of 77 species of terrestrial plants, about 50 different fish species, and 119 species of birds (Mumthaz and John 2017). A critically endangered fish species, *Ham-Buch (Pisodonophis boro*), has been discovered in the *pokkali* wetland habitat. Three endemic species namely *sun Catfish (Horabagrus brachysoma), Malabar pufferfish (Tetraodon travancoricus), and Oolari (Amblypharyngodon melettinus),* and five exotic species namely *Gambezi (Gambusia affinis), Tilapia (Oreochromis mossambicus), Catla (Catla Catla), Common carp (Cyprinus carpio),* and *Rohu (Labeo rohita)* were recorded from the wetlands (Deepa 2014). *Purple Moorhen* uses mangrove allies found in these wetlands as significant nesting material. The mangrove roots provide cover and, space for breeding, for a variety of aquatic creatures.

17 Climate Adaptability

Methods that bind the potential of the environment to bring adaptation assistance are broadly known as ecosystem-based adaptation (Bourne et al. 2016). An indigenous farming system is widely considered as an ecosystem-based adaptive strategy towards addressing climate change. The paddy-shrimp farming in *pokkali* fields reduces the environmental impact of farming. This cultivation differs greatly from conventional paddy farming. Unlike the conventional paddy system, the water gets tide-fed into and out of the fields at high and low tides. The continuous water exchange during the production cycle retains adequate oxygen in the fields and maintains an oxidized state rather than a reduced state thereby contributing to an adverse condition for methane production, as it happens in typical wetland paddy environments. Hence methane gas emissions from *pokkali* fields are less, reducing the contribution of Green House Gas emissions from the region (Ranjith et al. 2018).

The saline tolerance capacity makes *pokkali*, a climate-savvy system during floods too. The Pokkali rice plant, according to studies, can withstand salinity levels of six to eight grammes of salt in one litre of water (Manipadma 2017). The researchers from the International Rice Research Institute are actively working on producing new paddy varieties from the climate-adaptive *Pokkali* seeds for extending the cultivation across India's coastal districts Thomas (2019)

18 Evolving Challenges to *Pokkali* Farming System

Wetlands are disappearing at alarming rates around the world, despite the valuable ecological services and products they provide due to several anthropogenic activities. The growing risks of environmental change have made wetlands more vulnerable, worsening the living conditions of people who depend on these wetlands. The pokkali wetlands are currently at a number of tipping points, which refers to a condition in which an ecosystem transforms to another level or stage, over time (Prusty et al. 2017). The major challenges to *pokkali* farming system include alienation of land for commercial and infrastructure development, real estate development, pollution from industries, waste dumping and reclamation of wetlands, and a shift towards shrimp monoculture (Sudhan et al. 2016).

Since the 1960s, *pokkali* farming has been steadily declining in the State. The overall area under pokkali agriculture has reduced from 25,000 ha (Sreelatha and Shylaraj 2017) to about 8500 ha, according with Pokkali Land Development Agency. In this, only 5500 hectares are being used currently for farming. *Pokkali* paddy farming field covers 574 hectares in Thrissur, 1371 hectares in Alappuzha, and 3555 hectares in Ernakulam districts, respectively (Antony 2015). *Pokkali* fields are being converted for infrastructure development which includes roads, bridges, residential areas, or commercial activities (Vijayan 2016). The real estate boom has resulted in the reclamation and drainage of vast tracts of *pokkali* lands in the region.

Development often necessitates relocation while also jeopardizing environmental quality (Joy 2013). The Vallarpadam Container Transshipment Terminal and the auxiliary road and rail projects in Ernakulam have also irreversibly harmed the *pokkali* farming system in the region. As a result of this project, vast areas of *pokkali* lands underwent reclamation and conversion. Unscientific road planning, dumping of construction wastes, reclamation for rehabilitation, and real estate development contribute to wetland conversion in a short period (Chitra 2013). A considerable number of families who are dependent on *pokkali* fields for their livelihood were also got displaced (Joy 2019).

The majority of the *pokkali* tracts, are heavily contaminated by unscientific and uncontrolled emission of waste materials from different industries. For example, studies reveal that the Vembanad Lake, which is located along the Periyar River's Eloor-Edayar industrial belt, is a dumping ground for metals likes arsenic, cobalt, cadmium, mercury, nickel, and others (Joshy 2018). Also, the large amount application of chemicals for agricultural purposes and oil discharge from overboard engines of vessels have all aggravated the degradation of *pokkali* wetlands. Pesticides are sprayed by the contractors in shrimp farms on the day of harvesting to ensure stunning of shrimp to increase their catch (Prusty et al. 2017). In-situ preservation of salt resistant indigenous rice varieties and agricultural practises is difficult as a result of this. In recent years, the large net returns from Monoaqua-cultivation in pokkali lands have gained appeal, but in the long run, it is destructive to the area's social-ecological system. Unproductive measures have been introduced as a result of the continuous dispute between the agrarians and the fishing lobby. To prepare the fields, salty water must be pumped out, but breaches in the outer bunds occasionally occur, sparking concerns of sabotage (Pillai 2016).

Labour scarcity in *pokkali* fields has evolved as a major issue over the years. In a 2019 study among 150 *pokkali* farmers in Ernakulam district, 85% of the farmers said that the lack of farm labour was the most significant barrier to the farming system's continuation (Ranjith et al. 2018). The availability of alternative employment opportunities and high earnings in the nearby urban areas attract people more to it. Another factor for the workforce scarcity in the region is the local youth's predilection for white-collar occupation. The youth workforce is deterred from farming by non-agricultural employment options and the possibility of labour migration to other areas of the state, country, and abroad. Furthermore, other crops such as rubber, banana, coconut, cocoa, and others have proven to be less labour-intensive and yield larger earnings than *pokkali* which also resulted in the decline of the farming system (Ranga 2006). The transition of pokkali fields eventually led to the livelihood destruction of female farmhands (Shyna and Joseph 2000).

19 Conclusion

Kerala's traditional *pokkali* agricultural system is a highly sustainable farming approach. The different strategies and techniques employed in this cultivation contribute to the area's and stakeholders' environmental, social, and economic well-being. However, the socio-ecological significance of this farming system is still unidentified. Countless anthropogenic interventions and natural disasters lead to the decline of this sustainable cultivation system. Strong policy measures and comprehensive research are necessary to conserve the *pokkali* cultivation and achieving the SDGs through it.

Economic, institutional, social, and environmental sustainability are four equally essential components of sustainable development. Hence a development intervention strategy that is inclusive of all forms of sustainability is mandatory. The indigenous *pokkali* cultivation method is a model for long-term sustainability in socio-cultural, economic, and ecological realms. The *pokkali* farming system which generates local livelihood utilizes the available natural resources, there by reducting the expense for strting the farming activities. By offering sufficient price for the products, the pokkali system becomes a key anti-poverty strategy, ensuring the attainment of United Nations SDG1; poverty alleviation. Similarly, effective implementation of agri-aqua integration in farming can ensure water and food security for the local community in the region which in turn, supports to ensure food security and nutrition implied in SDG 2. SDG 5 will not be met unless women empowerment and gender equality are ensured. This is ensured by the farming system, which employs women as the main agricultural labourers (Rajan et al. 2008).

The *pokkali* farming system performs functions such as soil fertility protection, carbon dioxide storage, fossil fuel reduction, water conservation, flood control, landscape, and biodiversity preservation, etc. which contribute to environmental sustainability and climate change reduction. By following an organic model of agriculture based on ecological cycles and natural resources, the farming approach decreases the environmental impact of food production while keeping non-renewable resources to a minimum (Sasidharan et al. 2012). These characteristics help to accomplish SDGs 6, 7, and 8, which are sustainable water resource management, affordable, sustainable, and modern energy, and inclusive and sustainable economic growth, respectively. The high export potential of *pokkali* farming products aids in the inflow of foreign currency into the country, resulting in reduced inequality in the country and the realization of SDG 10 (Karunakaran et al. 2019). The rotational farming strategy used in *pokkali* fields allows waste material recycling without hurting the environment or water while also renewing soil life for long-term usage. These qualities underscore the relevance of *pokkali* farming in accomplishing SDGs 12, 13, and 14. SDG 15 is concerned with the preservation of land life. *Pokkali* wetlands are vital to the survival of life on Earth because of the incredible variety and environmental services they provide. As a result, wetland conservation initiatives help to achieve SDG 15 in a holistic way (Ranga 2006).

In this context, effective policy formation is critical to safeguarding the *pokkali* socio-ecological system. In addition to the social and ecological relevance to local development, the conservation of the *pokkali* farming system which falls in Vembanad wetlands, a Ramsar site, is significant to international and national wetland conservation and development. Interventions for the protection of indigenous farming systems entail a process of ongoing communication with policymakers at various levels, from local self-government to central government. Inherent conflicts in *pokkali* farming system which involves land ownership, seasonality in farming, water management for paddy and shrimp, marketing, and labour issues need to be addressed through grassroots level institutional strengthening and proactive interventions from state actors in the sectors of wetland conservation, water resources development, agriculture, and fisheries development.

A detailed inventory of wetland systems including *pokkali* lands needs to be developed towards ensuring wetland conservation in the state. Since the situation necessitates a bottom-up strategy for development, the state's ecologically sustainable "post-growth" development must be monitored through the strengthening of traditional communities or resource-dependent people and their indigenous knowledge systems. Farmers and local people should be made aware of the importance of preserving the ecological uniqueness of *pokkali* wetlands for mitigating the risks of climate change and consequent disasters. It is also critical to conduct periodic research covering indigenous farming practices, community livelihoods, local biodiversity, traditional water conservation practices, and developmental dilemmas in the region through interdisciplinary teams and participatory processes to produce practice-based evidence that can inform state policy. *Pokkali* farming system has proven itself to be an ideal social-ecological model ensuring socio-economic and ecological sustainability, but at present, stands affected due to the absence of participatory and environment-sensitive decision making in mainstream development processes. Facilitating the emergence of a strong environmental governance mechanism, which critically acknowledges the dynamic social and ecological exchanges in an indigenous farming system, and which attempts to translate the knowledge to policy and practice, can effectively redesign development practices towards the sustainability of *pokkali* farming.

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Agricultural Vulnerability and Adaptation Strategies by Farmers to Climate Change in South-Western Coastal Bangladesh

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1 Introduction

Increased concentrations of greenhouse gases (GHG), especially carbon dioxide (CO_2) in the atmosphere from anthropogenic activities have been causing climate change on a global scale, including rising temperatures and sea level rise (IPCC 2014). In addition to the increased temperature, climate change has also altered precipitation patterns, causing more frequent and intense climate extremes, biodiversity losses and inhibited habitation of low-lying coastal areas (Nicholls and Cazenave 2010; IPCC 2014). The changes in trends of temperature and precipitation from climate change cause a significant impact on crop yields (IPCC 2014; Huq et al. 2015).

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Coastal regions of tropical and subtropical Asia, such as the south-western coastal region in Bangladesh (SWCRB), are expected to be disproportionately and negatively impacted by climate change and sea level rise (Hansen et al. 2013; IPCC 2014, 2019). Additionally, SWRCB is particularly at risk due to its low elevation, confluence of three major rivers, and reduced supply of upstream freshwater from the Farakka Barrage (Mia 2009). The region experiences tidal surges, salinity intrusion, cyclones, droughts, floods and changes in the monsoon calendar (Dasgupta et al. 2015; BBS 2018).

For decades it has been highlighted that agricultural production in most developing countries is extremely vulnerable to climate change (Lansigan et al. 2000; Gbetibouo and Hassan 2005; Haim et al. 2008; Kabubo-Mariara and Karanja 2007; Moula 2009; Chen and Mueller 2018). In Bangladesh, agribusiness is the largest sector of the economy, representing approximately 14.23% of the absolute gross domestic product (GDP) and providing ~45.1% of the labour (BBS 2017, 2018). Bangladesh suffers an annual GDP loss of approximately 1.81% due to damage to food and cash crops from natural disasters. The total annual damage between 1990 and 2017 was estimated at $2.56 billion (Kabir et al. 2018). Salinity intrusion leads to agricultural losses and the salt-affected land has increased by approximately 27% between 1973 (83.3 million hectares) and 2009 (105.6 million hectares) (SRDI 2012).

SLR in Bangladesh is estimated to increase between 0.88 and 1.25 m by 2100; meanwhile, a SLR of 1 m is expected to submerge 20% of the coastal land of Bangladesh and lead to displacement of 20–30 million people (MoA 2013; Nishat and Mukherjee 2013; Sarwar 2013). For example, the last four cyclones Sidr 2007; Aila 2009; Bulbul 2019; and Ampan 2020 (Islam et al. 2021a, b) have caused many casualties; damage to the economy, the farming sector and to infrastructure, disruption to the ecology, loss of income for millions of people and forced relocation from the south-western coastal districts to other regions of Bangladesh (Shamsuddoha et al. 2013; Younus and Kabir 2018). SWCRB is particularly at risk due to its low elevation, the confluence of three major rivers and the reduction of upstream freshwater supply from the Farakka Barrage (Mia 2009). The region experiences cyclones, tidal surges, floods, drought, salinity intrusion, and changes to the monsoon patterns (Dasgupta et al. 2015; BBS 2018).

An assessment by the World Bank (2000) revealed that a 0.3 m (11.8 inch) SLR could result in a decrease of 0.5 ton in rice produce. The decline in crop production in coastal regions is especially due to the presence of salinity, which degrades the quality of soil and prompts land-use changes towards saline aquaculture, including shrimp and crab, or a mixed rice-shrimp approach (Paul and Vogl 2010; Brammer 2014; Khanom 2016). In the past, most farmers in Bangladesh grew rice 2–3 times per year, but now they can only produce rice once a year due to the increased salinity in the fields and changes in the rainfall patterns. In addition, oilseed, jute, and sugarcane production have ceased due to the salinization of farmland (Khanom 2016). Kabir and Golder (2017) observed that the overall decreasing rainfall trend can intensify salinization from reduced flow upstream of rivers, increased sedimentation in riverbeds and the resulting waterlogging caused by insufficient drainage.

As agriculture is particularly vulnerable, complex indicators are being developed to determine the susceptibility of agriculture to climate change (Neset et al. 2019). Although many studies have focussed on climate change, research focussing on the vulnerability of farmers to climate change in the SWCRB has not been conducted in depth (Shamsuddoha and Chowdhury 2007; Ahsan and Warner 2014; Islam et al. 2015; Huq et al. 2015; Bhuiyan et al. 2017; Quader et al. 2017; Younus 2017; Younus and Kabir 2018). Almost none of the earlier investigations have addressed the collective views of the coastal people regarding the vulnerability of agriculture (harvest, cattle, and fisheries) or considered the relationships between the diverse spatial impacts in the SWRCB region. Scarce literature has addressed local-based strategies of adaptation, as employed in the IPCC reports (2007), a gap this paper seeks to contribute to fill.

Besides, vulnerability is a complex phenomenon affected by climatic as well as non-climatic factors, political preferences, cultural and socio-economic backgrounds, and ecological features (Birkman 2007). Climate vulnerability is influenced by socio-economic and biophysical aspects and is exacerbated by the impacts of climatic stressors (O'Brien et al. 2009). In the context of climate change, vulnerability is described as a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007).

SWRCB has a highly fragile ecology; it has a high sensitivity and exposure, and a low adaptability. As represented in Fig. 1 , the combination of sensitivity and exposure leads to a potential negative impact (Fellmann 2012). Adaptive capacity is defined as the capability of a system to adapt to severe climatic conditions (IPCC 2007). Generally, the adaptive capacity of social systems depends on physical resources, access to information and technology, availability of support systems, institutional capacity, as well as on patterns of resource distribution (Yohe and Tol 2002).

This study was performed with the following objectives: (1) examine the effects of changing climate and SLR on agriculture and vulnerability in the SWCRB, (2) document the agricultural practices used in areas facing frequent and increased salinity, and (3) identify the methods adopted by farmers to adapt to and mitigate the effects of a changing climate, while examining the socioeconomic factors associated with different adaptation strategies. These objectives are studied using an analysis of vulnerability indicators through the perceptions of people living in the region.

Moreover, we hypothesize that farmers' vulnerability and adaptation are linked to climatic events, such as temperature, SLR, rainfall, droughts and riverbank erosion as well as other climatic events, such as salinity in addition to anthropogenic causes, such as shrimp farming. We assume that farmers will have limited adaptive capacity to adapt to the climate change impacts, furthermore, we rely on the judgment of the local population for future agricultural adaptation in the SWCRB that we test in this manuscript through the Multiple Logistic Regression (MLR) Model.

This research aims at contributing significantly to climate-induced hazard reduction and to generate and document knowledge on reducing the vulnerability of agriculture to climate change. It also aims to provide policy recommendations to decrease the vulnerability of farmers to the increasing effects of changing climate in the SWCRB.

2 Methodology

2.1 Study Area

The present study was performed in nine unions (Buri Goalini, Ramjan Nagar, Gabura, Kaikhali, Atulia, Ishwaripur, Munshiganj, Kashimari and Nurnagar) of the Shyamnagar Upazila of the Satkhira District in the SWCRB. Data was obtained from surveys completed in 320 households in these nine unions.

Farmers in this region typically cultivate Aman paddy, a monsoon dependent rice variety that is sown in June–July and harvested in December–January (Solidarités International 2017). For the rest of the year, due to high salinity, farmers can leave their land fallow for fish production, growing vegetables, or seeking alternative forest-based livelihoods. On an average, households in the region own between 0.13 and 0.2 ha of land, but most people in the coastal area are landless (Parvin et al. 2017). The size of land holdings is not sufficient to meet food and economic needs, so many farmers rent other lands to expand their farming capacity (Fig. 2).

The Bangladeshi climate consists of four seasons: pre-monsoon (March–May), monsoon (June–August), post-monsoon (September–November) and winter (December–February). Approximately 85% of the total rainfall (annual) occurs during monsoon (Hossain et al. 2014). The mean annual rainfall in south-western Bangladesh is 1.730 mm, 78% of which occurs within the monsoon months (Kabir and Golder 2017). Monsoon rainfall is essential for providing moisture to soil and sufficient water for irrigation, as well as eliminating soil salinity. Maximum temperature during pre-monsoon is ≥33 °C and the minimum temperature is 15 °C during winter (Rakib 2013). Rakib (2018) predicted an increase in temperature, and the temperatures over the SWCRB are expected to rise at a minimum by 1.26 °C and maximum by 2.16 °C by the end of the twenty-first century.

2.2 Rainfall and Land Data

2.2.1 Rainfall Pattern Changes

To analyse the changes in rainfall patterns, data was provided by the Bangladesh Water Development Board; a month-wise resolution record from 1968 to 2018 was retrieved from three different rain gauges, CL506, Cl508 and CL515, belonging to the SWCRB. Then, the monthly record was summed to create an annual record for each station. To analyse the trend changes per year, a linear regression was created for each of the three gauges using Holt's linear regression Equation (1957). This equation was originally intended to create a levelling-exponential method and a simple diagrammatic technique to allow a trend-based data forecast. However, here it was used to obtain the change in the trend of annual rainfall in millimetres.

2.2.2 Land Cover Analysis

To analyse the changes in the land cover and particularly, the increase in water levels, a supervised image classification was created for the Shyamnagar region in 1989, 1999, 2009 and 2019 using ArcGIS. This method was retrieved from Loog (2018), from a set of polygons containing training data. This training data gives the pixel values of the different satellite bands corresponding to different land uses. Then, the image classification algorithm uses this pixel information for the given land uses and tries to find similar pixel values to predict the land uses. Images used were retrieved from Landsat Image-United States Geological Survey; Google Earth Engine; Google Earth; GIS software 10.5, by collecting Landsat satellite imagery and three classifications were created: bare soil, water and vegetation.

2.3 Socioeconomic Data and Adaptation Methods

This study follows a mixed-method approach with the analysis of data (qualitative and quantitative) among vulnerable populations. A survey was conducted among farmers of 320 households of the Shyamnager Upazila in the Satkhira District of Bangladesh, to identify the current adaptive methods in practice by farmers faced with changing climate and its associated impacts. The households were surveyed using a close-ended questionnaire in a face-to-face interview. Participants were selected from nine unions (Buri Goalini, Ramjan Nagar, Gabura, Kaikhali, Atulia, Ishwaripur, Munshiganj, Kashimari, and Nurnagar).

In addition to the household survey, data was collected from 20 focus groups, 5 workshops, and interviews with key NGO and government representatives with different groups of pre-selected respondents of homogenous nature with semi-structured guideline and the use of participatory tranning. The guidelines prepared for each group of respondents purposely to draw out the specific information related to the research objective. Through focus groups, 17 farmers from 12 unions of the Shyamnagar Upazila of Satkhira District shared information about the crisis in agriculture in coastal areas. A descriptive analysis of the data, including average, percentage and frequency, was performed.

2.4 Multiple Logistic Regression (MLRM) Model

An MLRM model was used to study the correlation between a set of predictors, such as age, gender, and income, and the adaptive measures taken in response to reduce the responder's vulnerability (Hosmer and Lemeshow 1989; Menard 1995). In this particular analysis, the outcome was labelled as 0 (the outcome of interest is missing) or 1 (the outcome of interest is present). If p is the probability of the outcome being equal to 1, the Eq. 1 can be written as:

$$\hat{P} = \frac{\exp(b_0 + b_1X_1 + b_2X_2 + \cdots + b_pX_p}{1 + \exp\left(b_0 + b_1X_1 + b_2X_2 + \cdots + b_pX_p\right)} \tag{1}$$

where $\hat{P}$ is the predictable prospect of the existence of the result; b_0, b_1, b_2..., bp are the coefficients of regression; and X_1, X_2..., Xp are independent variables. In this study, four multiple regression equations were used. Dependent and explanatory variables, such as demographic, economic, and social characteristics of farmers (age, gender, and total earnings), were used to investigate the popularity of various adaptive measures. This equation, thus, compares the independent variables with the explanatory variables to estimate the extent to which the variables follow the same statistical trends of the explanatory variables (ibid).

Equation 2 is defined as follows:

$$\text{Adaptive Measures} = \frac{\exp(b_0 + b_1\text{Age} + b_2\text{Gender} + b_3\text{Total Earnings})}{1 + \exp(b_0 + b_1\text{Age} + b_2\text{Gender} + b_3\text{Total Earnings})} \tag{2}$$

where $\hat{P}$ represents various adaptive measures, such as the adoption of salt-tolerant livelihoods, adaptive mechanisms for farmers due to climate change, a variety of adaptations of coastal farms and risk preparedness related to induced SLR caused by changing climate; X_1 is age; X_2 is gender, and X_3 is total earnings (ibid).

3 Results

With global warming, temperature and precipitation patterns prominently impact crop productivity in the SWCRB (Huq et al. 2015). Increasing average temperature is a significant climatic parameter related to global warming, affecting the growth, development, and various physiological processes of crops (Fig. 3, Gornall et al. 2010). At the same time, pollination is lower due to higher temperatures, which reduces the honey available for harvest in the Sundarbans and affects the natural flowering cycle. Harmful diseases and pests have increased, especially around the Sundarbans (Akter et al. 2020). In addition, 45% of the people earn their living by working in various occupations related to the Sundarban forests, and are now facing huge threats. The increase in temperatures irritates the eyes of inhabitants (ibid).

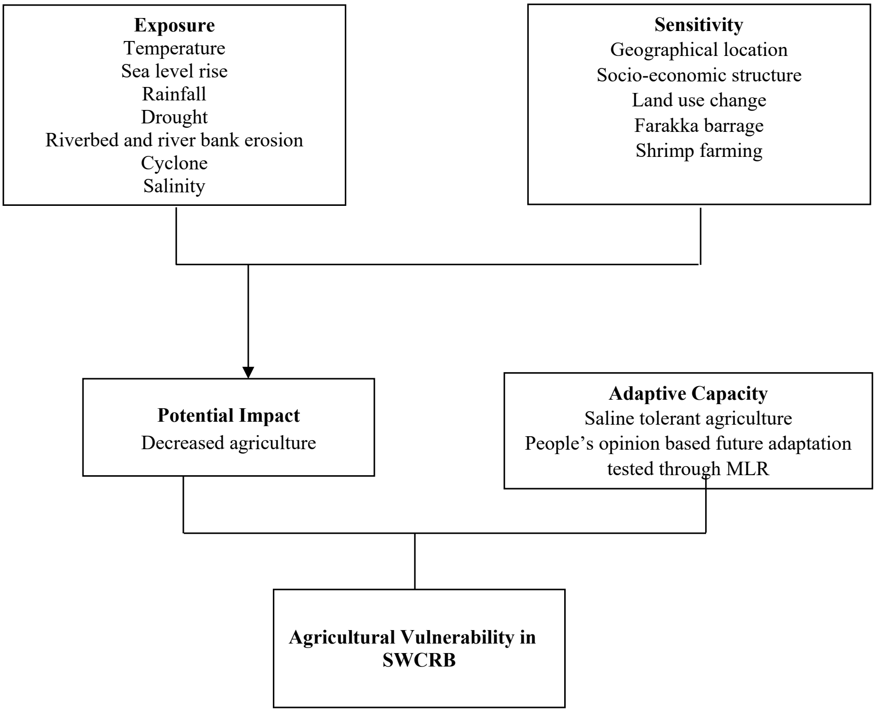


Fig. 1 Flowchart for vulnerability determination; retrieved from the IPCC 2007; Meybeck et al. 2012 (*Source* Authors' configuration)

3.1 Rainfall and Land Use Changes

The changes in land cover for Shyamnagar can be seen in Fig. 4, from 1989–2019, the Sundarbans are situated in the south, which possesses a majority of green cover classification. Most of the water expansion occurred in the southern region, where the majority of the population centres are located. This indicates that land has either been submerged or transformed into artificially sustained water bodies.

Based on the land cover analysis from 1989 to 2019, water cover has increased from 720,388 ha to 768,880, causing a 2.5% increase. Vegetation and bare soil land areas have decreased by 35,709 and 73,645 ha respectively, causing 1.82% decrease in land with vegetation and 3.86% reduction in bare soil. These changes are due to SLR and the creation of artificial water bodies for rice and shrimp farming (Table 1).

While the amount of land covered by water has consistently increased from 1989 to 2019 with small variations, changes in the bare soil and vegetation vary much more, both increasing and decreasing over time (Fig. 5).

At station CL515, a dramatic decrease of 11 mm of rainfall per year between 1968 and 2018 was observed, indicating a short-term decrease in overall precipitation levels. Similarly, station CL506 has seen a decrease in rainfall of 4 mm per year,

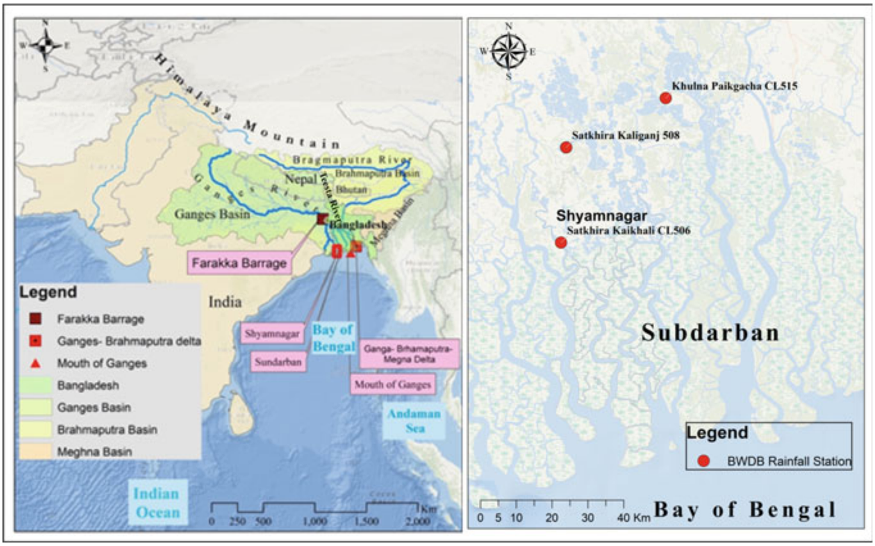


Fig. 2 Map of the geographical location of the Shyamnagar Upazila of the Satkhira District (12 unions) from the BWDB rainfall stations (*Source* Authors)

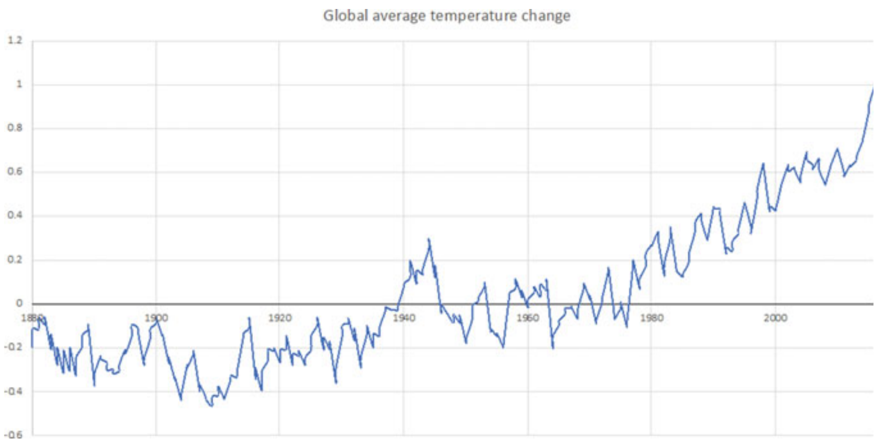


Fig. 3 Average global temperature changes from 1880 to 2015 (*Source* Authors with data retrieved from NASA, 2020)

which is not as substantial as station CL515 but a general decrease, nonetheless. In station CL508, it was found that rates did not change much, only by 0.15, indicating that they remained relatively constant. However, from these three records, there is a general decrease in rainfall with spatially different rates (Fig. 6).

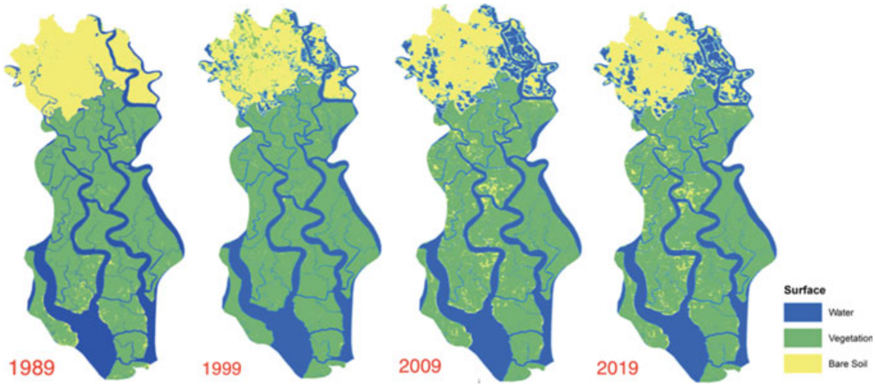


Fig. 4 Land cover maps showing changes from 1989–2019 (*Source* Authors' configuration)

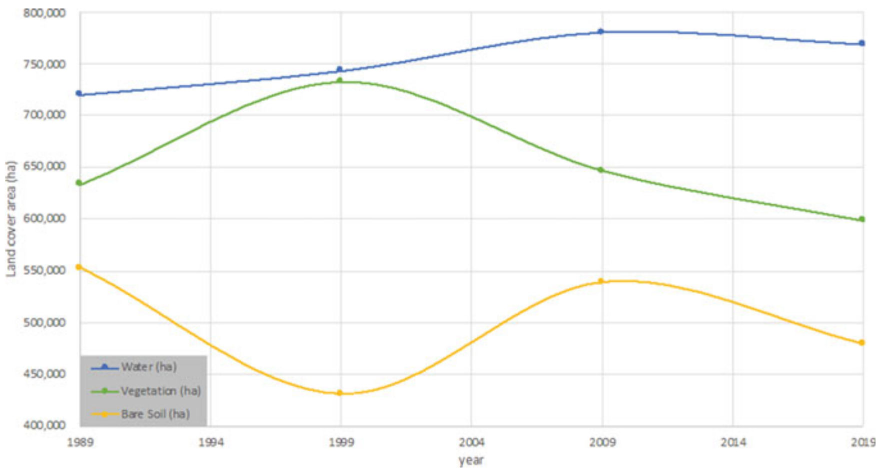


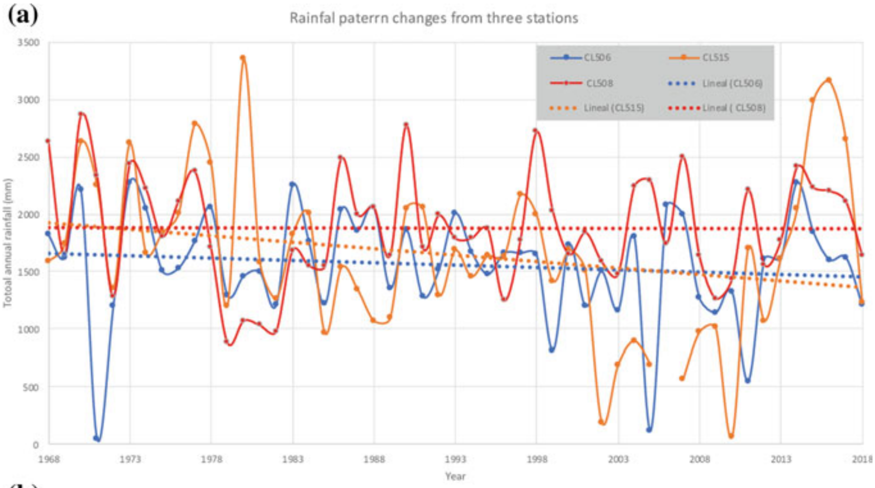
Fig. 5 Water, vegetation and bare soil land cover changes from 1989 to 2019. Self-made with data retrieved from USGS (Link: https://earthexplorer.usgs.gov) using ArcGIS software (Link: https://www.arcgis.com/)

3.2 Socioeconomic Data Summary

Of the farmers surveyed, 69.4% were men and 30.6% were women. On average, the households surveyed consisted of 4.99 persons. The households surveyed were 79% Muslim, 20% Hindu, and 1% other religions. Of the 320 households surveyed, 33.1% rely on fishing, 22.2% rely on day labour, and 15% rely on agriculture as their primary occupation, plus 36.9% as their secondary occupation. In these households, 89.1% of respondents also rely on a secondary occupation (Table 2).

Due to increased salinity ingress, population in the SWCRB is shifting from agriculture to other occupations, apart from most landowners, who are driven by

(a)



(b)

Station	annual average rainfall trend
CL506	-4.1523
CL515	-11.2111
CL508	-0.1508

Fig. 6 **a** Changes in annual average rainfall patterns from 1968 to 2018 at three different stations: CL506, CL508 and CL515, along with the annual trend change. **b** Self-made with data retrieved from the BWDB (*Source* Authors)

Table 1 Showing land use changes

	1989	1999	2009	2019	% change
Water	720,388	743,414	780,785	768,880	+2.5%
Vegetation	633,604	732,284	646,853	598,895	−1.82%
Bare Soil	553,561	431,856	539,778	479,916	−3.86%

Table 2 Primary and secondary occupations of survey respondents

	Primary occupation	Secondary occupation
Fishing	106 (33.1%)	68 (21.3%)
Day labour	71 (22.2%)	32 (10%)
Agriculture	48 (15%)	118 (36.9%)
Others	38 (11.9%)	24 (7.5%)
Driver	23 (7.2%)	25 (7.8%)
Service holder	17 (5.3%)	0 (0%)
Livestock	10 (3.1%)	18 (5.6%)
Grocery store	7 (2.2%)	0 (0%)
None	0 (0%)	35 (10.9%)

Field work 2018–2019

profitable incomes. Middle- and lower-class families have to provide for their basic needs with other types of occupations. Also, influential landlords utilize the landless farmers as farming labourers, and they farm shrimps and crab farming instead of cultivating the fields. Coastal people are shifting from farming to non-farming activities due to climate change (Rana and Titumir 2014).

In a case study, Babul Bepari, 40 years old share farmer of Gosairhat of Panchkathi village, lives with his wife and five children. He must share 50% of his total production with the landowner. His family depends on rice from the common land and vegetables grown at home. His family occasionally consumes protein, maybe once a week. During the Rabi season, Bepari grows BORO rice. About five years ago, he produced 0.4 metric tons on his farmland and shared 0.2 metric tons with the landowner. But recently, his production has dropped dramatically. Last year, he could only produce 0.08 tons from the land in the same area during the dry season, and he had to share 0.04 tons with the landowner. The rice that was left wasn't enough for the entire family and he had to spend approx. 3000 takas ($320) to buy the remaining rice. He managed to get more money by limiting the budget for other household expenses. The decline in food production during the dry season forced him to limit the diversity of his diet, which eventually led to malnutrition among his family members.

The percentage decrease in crop production is much higher than the percentage loss of cultivable land, because half of the year, the same land is used for shrimp cultivation, and therefore, farmers cannot cultivate two rice crops on the same land. Salinization has ceased the production of jute, oilseed, and sugarcane, resulting in a change in land use to saline aquaculture, like shrimp farming or rice and shrimp cultivation, which have a negative impact on the environment (Khanom 2016). In the SWCRB, one Kharif crop is grown every year and famine is said to have a severe impact on both the germination and vegetative development phases (Huq et al. 2015). The Kharif rice crop is likely to decrease in the SWCRB. As salt-tolerant rice is not cultivated by all growers due to a lack of understanding and support, an insufficient number of farmers have successfully grown salt-resistant Kharif rice (Khanom 2016).

An analysis by Bangladesh Agricultural Research Council (BARC) (Islam 2004) revealed that a decrease in wheat production equal to 586.75 million USD would result from salinization. A high projected sea level rise of ~88 cm (35 inches) would cause flooding in the agricultural areas, especially the lowlands and deltas in some regions of Bangladesh. The soil quality in farmlands in coastal regions is likely to be severely degraded, and floods will cause a loss in agricultural productivity on the coastal lands (Chen and Mueller 2018).

In this study, the nature of household food security was classified using the Household Food Insecurity Access Scale (HFIAS). Households were divided into four levels of food insecurity (access) through the HFIAS: food secure, mildly, moderately and severely food insecure. A higher HFIAS score indicated lower chances of obtaining food and a greater food insecurity faced by the household, and a lower HFIAS score indicated higher chances of obtaining food. Few households (13.4%) are food secure among the households surveyed (Table 3). The vast majorities of the population have low incomes and are vulnerable to climate change and suffer from widespread food insecurity.

Table 3 Food security and economic status among survey respondents; data from the field survey of 2018 to 2019 (*Source* Authors)

Economic status	Food security Status				Total (%)
	Food secure (%)	Mildly food insecure (%)	Moderately food insecure (%)	Severely food insecure (%)	
Upper class	3.4	0.0	0.0	0.0	3.4
Middle class	10.0	13.8	10.6	0.0	34.4
Poor	0.0	0.0	32.2	8.4	40.6
Extremely poor	0.0	0.0	0.0	21.6	21.6
Total	13.4	13.8	42.8	30.0	100.0

3.2.1 Farmers' Identification of Climate Change Impacts

Household survey data was used to analyse how farmers anticipate the changing climate and modify their adaptive measures to mitigate its impacts. Household participants were asked to identify the effect of SLR and changing climate on them. They chose from a list of possible impacts and were allowed to select more than one option. Participants identified frequent natural disasters (93.1%), negative impacts on agriculture (75%), and loss of land (32.8%) as negative impacts that they faced due to climate change (Tables 4 and 5).

Of the households surveyed, 85% reported that their farmland had been negatively impacted by changing climate and SLR. Respondents indicated that, in the study area, majority of the population is involved in labour, farming, and fish catching.

Table 4 Impacts households face from rising sea level and changing climate

Change of impacts from climate change	Count[a]	% Respondents (%)
Frequent natural disasters	298	93.1
Negative effects on agriculture	240	75.0
Loss of land	105	32.8

[a]Field survey 2018–2019; Multiple response (*Source* Authors)

Table 5 Respondents' perception regarding the effect of rising sea level and changing climate on agricultural lands, self-made with data from field survey (2018–2019). Was the agricultural land in your area affected by CC and SLR?

Yes	85%
No	15%

Field survey 2018–2019 (*Source* Authors)

Due to climate change, SLR, climate change and different natural calamities (such as cyclones, floods, and salinity intrusion) causes a delay in timely planting and harvesting paddy, causing losses. As a consequence, they have been compelled to change their agricultural livelihood patterns, leading to temporary or permanent food insecurity in the SWCRB (Khanom 2016).

Specifically, a farmer from the Paddapukur Union X with age 51 reported that his family lost their cropland, house, cattle, and belongings during cyclone Sidr (2007). Cyclone Aila (2009) resulted in 330 deaths, 6207 missing people, and >1 million homeless people. Additionally, a local journalist, Y reported that cyclone Bulbul (2019) damaged 5018 fishing grounds; 10,000 ha of transplanted aman paddy; 2000 he of other crops such as vegetables, betel, and mustard, and many mud houses.

Respondent Z of Kashimari Union said that salt water entered the villages of Sankarkathi, Kachiharania, Gobindpur, Joynagar, Kashimari, Ghola, and Godara, all of which are in 1 to 9 wards of the union; due to the lack of strong dams and drainage systems, approximately 1250 ha are unsuitable for crop production, which has commanded to a nutrition mishap.

From the focus group discussions (FDGs), this research revealed that the inclination of the conditions for classifying vulnerable farmers in Shaymnagar Upazila are: (1) Twelve unions are disaster-prone, (2) Most farmers have been severely affected by floods, cyclones, riverbank erosion, SLR, and soil and water salinity over the past two decades and still currently, (3) Significant deterioration of livelihoods with very little to no coping strategies or recovery, (4) Poor and irregular income source <5000 Bangladesh Taka (BDT) like 55.55 $US per month, (5) Land ownership <0.5 acres, (6) Inability to obtain adequate food sources, (7) Socially fragile.

3.2.2 Extensive Area Saltwater Expansion: A Situation Analysis Through FGDs and Workshops

The Burigoalini Union is located in the heart of the area that is surrounded by limestone and the Kholpetua rivers. The shrimp farming area covers 2639 ha, and the agricultural area is 650 ha. Shrimp farming started in the coastal area in the 1990s, since then, salt water has spread to most of the union territory, resulting in direct and indirect loss of fresh water sources in the 8 villages of Vamiya, Porakatla, Durgabati, Nildumur, Datinakhali and Kalbari. Several indigenous rice species, fish, and agriculture are almost extinct. The impact of the salinity in agriculture: 10% of people of the union started cultivating rice and vegetable varieties that are salt-tolerant, in shrimp farms and paddy fields, due to the loss of indigenous rice, fish and yield diversities. Currently, new diseases, pests and insects have proliferated in agriculture. Canals and rivers have become clogged due to illegal occupation. There are 9 small and large canals in the union, including illegal shrimp and settlement routes. The expansion of salt water has reduced agricultural land in the area by 10%.

3.2.3 Impact of Rainfall Changes on Agriculture

As shown in Table 6, respondents reported that the impacts of rainfall changes result in: loss of agriculture and biodiversity (51.60%), economic losses (44.70%), negative impacts on health (39.10%), food insecurity (37.50%), changes in livelihood patterns (34.40%), damage to fisheries (31.30%), and damage to houses (30.30%). Agriculture is heavily dependent on rainfall patterns, and delayed monsoon rains alter the timing of transplanting and harvesting periods, increase crop failure, reduce food production and increase the demand for food purchase and other capital (labour, money, fertilizer, etc.) Respondents also reported that during periods of heavy rainfall, people employed in fishing and agricultural industries cannot work, and some may even migrate temporarily or permanently to other regions for employment.

Respondents indicated that the agricultural sector and crop production are affected by low rainfall intensity during monsoon periods, which exacerbates drought; also, high rainfall intensity during post-monsoon periods causes flooding of rivers and canals and leads to waterlogging of nearby agricultural chattels. SLR, storm surges and cyclones enhance saltwater intrusion, which reduces the amount of freshwater available for irrigation and result in reduced crop making. Respondents reported that traditional cultivation methods are also changing due to climate change, as rice production in Aman (winter) is delayed due to waterlogging. Farmers are therefore unable to transplant and harvest rice in time for the new crops in the Rabi season. Farmers now fallow their land during the Rabi season because of the shortened growing season and the risk of crop loss due to the pre-monsoon rains and cyclones (in May). Three respondents (X, Y and Z of the Bhurulia, Atulia and Shyamnagar Unions) respectively confirmed that 22 villages in the Shyamnagar Upazila were flooded due to cyclone Amphan on May 20, 2020. The floods are also damaging infrastructure and more than 40 km of dams have failed in 21 places out of 121 km of embankments. Due to increased soil salinity, approximately 331,200 acres of cultivable land in the Shyamnagar Upazila were severely damaged; 121,360 people suffered financial losses, food shortages and nutrition deficiencies; and more than 64,000 people were displaced (Respondents: X, Y and Z). Some local farmers said that the paddy sheaf had been cut due to a lack of rain for a long time. Due to a shortage of rainfall, more chemical fertilizers have to be added to the soil, which has also increased fuel consumption.

Respondent X, a farmer from Gabura Union, said that mango buds, jackfruit flowers, mangoes, and lemon flowers have dried up and paddies are getting less than 185 kg per bigha (0.6198347 Acre) due to drought. In addition to crops, cattle have been affected by various diseases. He said that before, we used to get good rains around this time of the year, but this year (June 2019), there is no rain.

The changes in water availability are caused by changing climate in addition to socio-political factors. In this study, 88% of the respondents confirmed that the Farakka Barrage exacerbates the problems caused by climate change. The Farakka Barrage was built by India, along with many other hydraulic initiatives to dam and use rivers that were previously shared by India and Bangladesh, and these have had profound ecological consequences for Bangladesh (Kawser and Samad 2016).

Table 6 Results of multiple logistic regression model of covariates of different measures adopted by the coastal populations for salinity-tolerant livelihoods (*Source* Authors)

Parameter estimates

Measures adopted for saline tolerable livelihood	Independent variables	B	Std. Error	Wald	Df	Sig	Exp (B)	95% Confidence interval for Exp (B)	
								Lower bound	Upper bound
Crab cultivation	Gender	0.346	0.319	1.176	1	0.278	1.413	0.756	2.639
	Age	0.013	0.011	1.311	1	0.252	1.013	0.991	1.035
	Total earning	0.000	0.000	0.073	1	0.788	1.000	1.000	1.000
Crops	Gender	−1.211	0.44	7.577	1	0.006	0.298	0.126	0.705
	Age	−0.003	0.012	0.042	1	0.838	0.997	0.973	1.022
	Total earning	0.000	0.000	4.256	1	0.039	1.000	1.000	1.000
Others	Gender	0.216	0.91	0.056	1	0.812	1.241	0.208	7.393
	Age	−0.001	0.032	0.001	1	0.977	0.999	0.938	1.065
	Total earning	0.000	0.000	0.065	1	0.799	1.000	1.000	1.000
No answer	Gender	0.613	0.351	3.055	1	0.08	1.846	0.928	3.672
	Age	0.02	0.012	2.669	1	0.102	1.02	0.996	1.045
	Total earning	0.000	0.000	2.438	1	0.118	1.000	1.000	1.000

a. The reference category is: Shrimp or fish enclosure

Model fitting information

Model	Model fitting criteria	Likelihood ratio tests			Pseudo R-Square
	−2 Log likelihood	Chi-Square	Df	Sig	(Cox and Snell)
Intercept only	770.040				

(continued)

Table 6 (continued)

Parameter estimates

Measures adopted for saline tolerable livelihood	Independent variables	B	Std. Error	Wald	Df	Sig	Exp (B)	95% Confidence interval for Exp (B)	
								Lower bound	Upper bound

Final	738.490	31.550	12	0.002	0.094
Goodness-of-fit					
Pearson		862.770	780	0.021	
Deviance		642.943	780	1.000	

Survey respondents reported that the Farakka Barrage caused drought during the dry season (53.1%), river overflowing during the monsoon season (40.6%), as well as other effects (6.2%). The limited water flow in the River Ganga during the dry months is negatively affecting activities such as navigation, farming, forest management, fishing, and further enhancing saltwater intrusion. The abundance of water in the wet season causes flooding and waterlogging problems. Fluctuation between too much and not enough water at different times in the season has been increasingly deteriorating the socio-economic status of the region's inhabitants.

3.2.4 Climate Change and Fish Farming

In this study, 97% of respondents stated that the availability of fish has substantially reduced as a result of changing climate. The major cause for the reduced fish availability is the migration of the hilsa fish (*Tenualosa ilisha)* to less saline water to lay eggs for reproduction. Compared to the previous 15 years, 41% of respondents reported a 40 to 60% decrease in fish, and 34% of all respondents reported a 21 to 40% reduction in fish. Combined, this means that 75% of all respondents indicated that the decrease in fish was between 21 and 60%. Production of Hilsa fish (Tenualosa ilisha) in inland rivers waters has decreased in ~20 years by ~20%; the marine yields have tripled, and the main hilsa catches are now taken in marine waters rather than inland waters (Hossain et al. 2018a, b). The respondents also revealed that the main causes of fish decrease are the increase of water temperatures and salinity, lack of freshwater, destruction of ecosystems, and reduction of dissolved oxygen in the water.

3.2.5 Impact of River Erosion on Agriculture

Although embankments are built around rivers to prevent river erosion, many of them break due to excess water and destroy nearby cropping. According to the survey, 86% of respondents stated that their land was not protected by the embankments. In addition, respondents identified the undesirable impacts of riverbed and river bank erosion with loss of farmlands and homesteads (63.10%) and loss of crops (55%).

3.3 Strategies for Adaptation to Changing Climate

From the households surveyed, 20.6% of respondents reported that farmers from the study area have utilized different strategies for minimizing climate change impacts on agriculture, 71.6% did not use adaptation measures, and 7.8% were unsure. In this study, 73% reported that adaptation strategies are insufficient to reduce the severity of changing climate on agriculture, especially near the coasts.

Many adaptation strategies have been implemented, which include constructing dams around agricultural land, rainwater harvesting, and proper drainage, cultivation of HYV crops, homestead gardening, livestock farming, and community supported agriculture (CSA). In order to adapt to salinity-tolerant livelihoods, 33.8 and 25.6% of the total respondents agree that adaptation measures include respectively shrimp, fish and crab farming. Moreover, 19.7% of respondents agree that coastal residents are growing salt-tolerant crops rather than traditional varieties. Aside from growing salt-tolerant crops, other adaptive measures include raising a plinth of tube-wells and the houses themselves, as well as rainwater harvesting and afforestation (Hossain et al. 2018a, b).

Respondents indicated that farmers have repeatedly failed to cultivate rice in the rice fields owing to increased salinity in soil and limited availability of irrigation water. The farmers cultivate rice varieties that are salt-tolerant, such as BINA-8 and BRRI-54, which have a higher production output than ordinary rice (BR-11). BINA-8 only needs two months to mature and can be cultivated in June; however, BINA-8 variety matures so quickly that, when planted between plots of other varieties, the rice crop harms the newly planted crops. Other rice varieties include BRRI Rice-28 and 30, and BR-10, 11, 22, and 23; additionally, small-scale farmers grow and harvest various locally available varieties of rice, such as Purbachi and canned rice. Farmers also use drip pipe irrigation systems to grow vegetables on the dams surrounding the freshwater fish farms (Haque et al. 2019).

Household participants were asked what is the best adaptation measure to increasing salinity, and 34% responded shrimp or fish production, 25% crab cultivation, 20% salt-tolerant crop production, and 19% had no answer (Fig. 7). Other alternatives to agricultural land use are increasing, such as planting mangrove trees (like Golpata—Nypa fruticans and kaora—Sonneratia apetala), cultivating salt-tolerant grass and mele reed (Cyperus Tagetiformus), and cultivating floating gardens. One

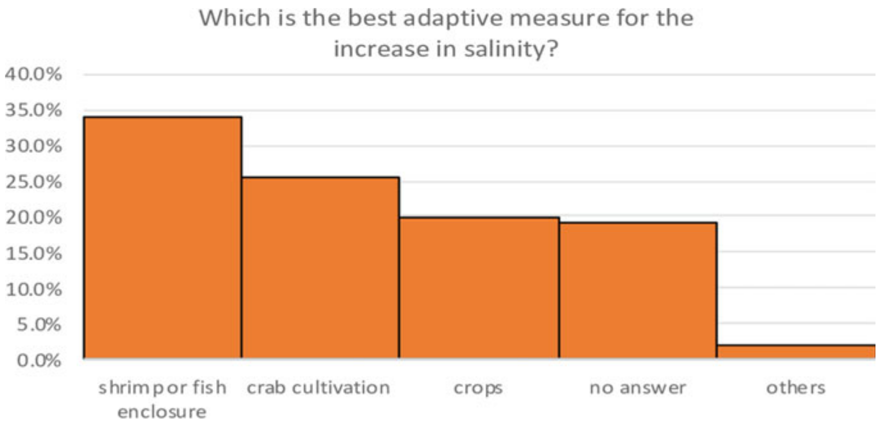


Fig. 7 Household survey respondents' views on salinity adaptation measures (*Source* Authors)

respondent determined that locally available rice varieties, including Hamai, Kajal-shail, and Nonakachi, are favourable for plantation. These results indicate that the HYV, which is salt-tolerant, may not adequately adapt to rising salt levels in the soil and reveal that farmers are reluctant to choose traditional local rice varieties.

3.3.1 Secondary Effects of Adaptation Measures in Response to Changing Climate

The evolving tendency of using agricultural land for shrimp farming has increased over the last two decades especially for economic purposes and as an adaptation approach to changing climate and salinity ingress. Though shrimp farming has provided a viable adaptation measure to climate change, it has caused further environmental problems that are acerbating the impacts of climate change for surrounding farmers (Prodhan et al. 2017). Household participants in the survey reported changes in land use due to shrimp production, including loss of native vegetation, salinity increase, changes to soil texture and pH, among other impacts (Dasgupta et al. 2015).

Based on the research conducted, 303 out of 320 interviewees (94%) agree that removing or controlling the expansion of shrimp farming on farmlands is a prominent adaptation strategy for minimizing saltwater ingress and improving crop productivity. Interviewees also agreed that the construction of high dams or embankments along rivers would help control the flooding of farmland by salt water. From the survey, 72.50% of respondents agree that shrimp cultivation primarily causes aquatic pollution at the local level resulting in a potable water crisis. For example, in the Gabura Union, > 95% of the land is used to grow shrimp, and approximately 3000 families were deprived of drinking water due to canal closure to stop the use of illegal nets.

A survey respondent (Safali Begum from the Ramjan Nagar Union) reported that more farmers in the area are farming shrimp, because it represents half the work of a day labourer, compared to the same amount of work in a rice paddy. Furthermore, shrimp farmers add salt to the water to improve shrimp growth, which increases the salinity in the water and soil, causing reduced agricultural productivity (Paul and Vogl 2010; Parvin et al. 2017). The main concerns with salinity are changes in land use practices, restrictions on rice production, loss of local grain and vegetable varieties, soil depletion, and overall reduction in the growth of the agricultural sector (Prodhan et al. 2017).

3.4 The Influence of Socio-Economic Factors in Adaptation

The associations of various socio-economic parameters of respondents (including age, gender, total income) with their adaptive measures were analysed using MLRM. Regression analysis was employed to study the impact of earnings, age-group, and gender on (1) adopted adaptation practices, (2) respondents' perceptions of the best options for adaptation strategies and, (3) perceptions of the best options for disaster preparedness.

A model was created to compare the impact of age, gender, and total earnings on adaptation strategies, such as crab cultivation, salt-tolerant crops, and others, compared to shrimp or fish farming. Total income had a significantly positive effect on the cultivation of salt-tolerant crops compared to shrimp or fish farming (Table 6). The final model was significant [chi-square (12) = 31.550, $p < 0.05$]. The Pearson's chi-square test indicates a poor data fit [chi-square (780) = 862.770, $p = 0.021$], whereas the Deviance indicates a good data fit [chi-square (780) = 642.943, $p = 1.00$].

Two models were created to analyse the impact of age, gender, and earnings on different perceptions of numerous climate change adaptive mechanisms. The first of these two models compare respondents' perceptions of climate justice, boat availability, tree plantation, places for shelter, environmentally friendly shrimp farming, awareness and planning, help from an NGO and the government as compared to the adaptation strategy using salt-tolerant crop production (Table 7).

The age of respondents had a significant influence on adaptive measures, such as 'boat availability, 'climate justice', 'tree plantation', 'places for shelter', 'help from an NGO', and 'awareness and planning'. In addition, the gender of respondents had a significant influence on 'tree plantation', 'environmentally friendly shrimp farming', and 'places for shelter' as measures against CC, compared to 'plantation of salt-tolerant crops'. The model fit indicates that the final model significantly improves in terms of fit as compared to the null model [chi-square (24) = 58.833, $p < 0.001$]. Pearson's chi-square test showed that the model did not fit the data well [chi-square (1560) = 2264.38, $p = 0.000$], whereas the Deviance chi-square indicated a good data fit [chi-square (1560) = 1004.009, $p = 1.00$].

The second model was created to analyse perceptions of adaptation measures, comparing perceptions of rainwater harvesting, adequate drainage to eliminate prolonged salt waterlogging, control of new shrimp farms cultivation besides enhancing salt-tolerant crops, homestead gardening and floating crops, employment of farmers through institution building, government as well as NGO programmes, community-focussed projects on adaptation, livestock farming, including alternative sources of income to the adaptation strategy moreover building a dam or dike around agricultural fields (Table 8).

The covariates analysis of the current adaptive measures of coastal farmers to CC and SLR reveals that the gender of the respondents had a significant influence on the adaptation measure for 'aggression control of new shrimp farms', compared to 'building of dam'. The age of respondents also had a significant influence in adopting the measure of "alternative sources of income". The final model is non-significant [chi-square (30) = 26.489, $p > 0.05$], the Pearson's chi-square test showed a good data fit [chi-square (1950) = 1840.108, $p = 0.963$], and the Deviance chi-square indicated good fit [chi-square (1950 = 1035.514, p =1.00].

The last model was created to analyse the covariates of preventative measures used by people to cope with the hazards of changing climate. The age of the participants was significant in the preparedness measure of cyclone. The total income of

Table 7 Multiple logistic regression model (MLRM) of covariates of different people's perception /opinion on farmers' current adaptive mechanisms due to CC (*Source* Authors)

Present adaptive measures	Independent variable	B	Std. Error	Wald	Df	Sig	Exp (B)	95% Confidence interval for Exp (B)	
								Lower bound	Upper bound
Climate justice	Gender	−0.620	0.354	3.074	1	0.080	0.538	0.269	1.076
	Age	−0.026	0.013	4.103	1	0.043	0.975	0.951	0.999
	Total earning	0.000	0.000	0.463	1	0.496	1.000	1.000	1.000
Availability of boat always	Gender	0.124	0.445	0.078	1	0.780	1.132	0.473	2.707
	Age	−0.037	0.017	4.966	1	0.026	0.964	0.933	0.996
	Total earning	0.000	0.000	0.148	1	0.700	1.000	1.000	1.000
Tree plantation	Gender	−2.187	0.795	7.573	1	0.006	0.112	0.024	0.533
	Age	−0.062	0.020	10.128	1	0.001	0.940	0.904	0.976
	Total earning	0.000	0.000	0.908	1	0.341	1.000	1.000	1.000
Place for shelters	Gender	−1.365	0.569	5.757	1	0.016	0.255	0.084	0.779
	Age	−0.039	0.018	4.792	1	0.029	0.962	0.929	0.996
	Total earning	0.000	0.000	0.006	1	0.939	1.000	1.000	1.000
Environmentally friendly shrimps farming	Gender	−2.189	1.094	4.009	1	0.045	0.112	0.013	0.955
	Age	0.010	0.025	0.156	1	0.693	1.010	0.962	1.060
	Total earning	0.000	0.000	2.412	1	0.120	1.000	1.000	1.000
Awareness and planning	Gender	0.739	0.618	1.428	1	0.232	2.094	0.623	7.036
	Age	−0.086	0.027	9.939	1	0.002	0.918	0.870	0.968

(continued)

Table 7 (continued)

Present adaptive measures	Independent variable	B	Std. Error	Wald	Df	Sig	Exp (B)	95% Confidence interval for Exp (B)	
								Lower bound	Upper bound
	Total earning	0.000	0.000	0.166	1	0.683	1.000	1.000	1.000
By the help of NGO	Gender	−0.876	0.649	1.822	1	0.177	0.416	0.117	1.486
	Age	−0.055	0.023	5.872	1	0.015	0.946	0.904	0.989
	Total earning	0.000	0.000	0.000	1	0.997	1.000	1.000	1.000
Help by government	Gender	−0.449	0.673	0.445	1	0.505	0.638	0.171	2.385
	Age	−0.034	0.024	2.052	1	0.152	0.966	0.922	1.013
	Total earning	0.000	0.000	0.151	1	0.698	1.000	1.000	1.000

a. The reference category is: Planting of saline tolerable crop/agriculture

Model fitting information

Model	Model fitting criteria	Likelihood ratio tests			Pseudo R-Square
	−2 Log likelihood	Chi-Square	Df	Sig	(Cox and Snell)
Intercept only	1127.419				
Final	1068.586	58.833	24	0.000	0.169

Goodness-of-fit

	Chi-Square	Df	Sig	
Pearson	2264.384	1560	0.000	
Deviance	1004.009	1560	1.000	

Table 8 Multiple logistic regression model (MLRM) of covariates of different people's perception /opinion on coastal farmers' current adaption to SLR induced by CC (*Source* Authors)

Parameter estimates									
Adaption variety in coastal farmers to climate change induced SLR	Independent Variables	B	Std. Error	Wald	Df	Sig	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower bound	Upper bound
Rainwater harvesting for drinking and irrigation	Gender	−0.518	0.572	0.821	1	0.365	0.596	0.194	1.826
	Age	−0.013	0.021	0.363	1	0.547	0.987	0.948	1.029
	Total earning	0.000	0.000	0.03	1	0.863	1.000	1.000	1.000
Proper drainage to remove prolonged saline water logging	Gender	−0.901	0.607	2.201	1	0.138	0.406	0.124	1.335
	Age	−0.01	0.022	0.209	1	0.647	0.99	0.949	1.033
	Total earning	0.000	0.000	0.059	1	0.808	1.000	1.000	1.000
Control the aggression of new shrimp farm	Gender	−1.564	0.737	4.502	1	0.034	0.209	0.049	0.888
	Age	−0.034	0.024	1.999	1	0.157	0.966	0.921	1.013
	Total earning	0.000	0.000	0.729	1	0.393	1.000	1.000	1.000
Cultivation of saline tolerant HYV crops	Gender	−0.845	0.726	1.356	1	0.244	0.429	0.103	1.782
	Age	−0.019	0.026	0.533	1	0.465	0.981	0.932	1.033
	Total earning	0.000	0.000	0.002	1	0.964	1.000	1.000	1.000
Homestead gardening and floating cultivation	Gender	−0.727	0.577	1.588	1	0.208	0.483	0.156	1.498
	Age	0.003	0.021	0.019	1	0.889	1.003	0.963	1.045
	Total earning	0.000	0.000	0.042	1	0.838	1.000	1.000	1.000
Employment of farmers through capacity building	Gender	−0.956	0.666	2.058	1	0.151	0.385	0.104	1.419
	Age	0.004	0.023	0.026	1	0.871	1.004	0.959	1.051

(continued)

Table 8 (continued)

Parameter estimates

Adaption variety in coastal farmers to climate change induced SLR	Independent Variables	B	Std. Error	Wald	Df	Sig	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower bound	Upper bound
	Total earning	0.000	0.000	0.538	1	0.463	1.000	1.000	1.000
Govt. and NGO facilities (subsidy, credit, insurance etc.)	Gender	−0.735	0.872	0.712	1	0.399	0.479	0.087	2.646
	Age	0.011	0.031	0.136	1	0.712	1.011	0.952	1.074
	Total earning	0.000	0.000	1.091	1	0.296	1.000	1.000	1.000
Perform community-based adaptation options	Gender	−0.703	0.729	0.929	1	0.335	0.495	0.119	2.068
	Age	0.016	0.025	0.417	1	0.519	1.017	0.967	1.068
	Total earning	0.000	0.000	0.379	1	0.538	1.000	1.000	1.000
Livestock Farming	Gender	-0.45	0.585	0.593	1	0.441	0.637	0.203	2.006
	Age	-0.009	0.021	0.177	1	0.674	0.991	0.95	1.033
	Total earning	0.000	0.000	0.109	1	0.741	1.000	1.000	1.000
Alternative sources of income	Gender	-1.148	0.952	1.456	1	0.227	0.317	0.049	2.048
	Age	-0.071	0.036	3.775	1	0.052	0.932	0.867	1.001
	Total earning	0.000	0.000	0.019	1	0.89	1.000	1.000	1.000

a. The reference category is: Construction of dam/dyke around agricultural land

Model fitting information

(continued)

Table 8 (continued)

Parameter estimates									
Adaption variety in coastal farmers to climate change induced SLR	Independent Variables	B	Std. Error	Wald	Df	Sig	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower bound	Upper bound

Model	Model fitting criteria	Likelihood ratio tests			Pseudo R-Square
	−2 Log likelihood	Chi-Square	Df	Sig	(Cox and Snell)
Intercept only	1213.347				
Final	1186.858	26.489	30	0.65	0.08
Goodness-of-fit					
Pearson		1840.108	1950	0.963	
Deviance		1035.514	1950	1	

respondents was a significant variable in the adoption of the measure of ‘supporting houses with bamboo and ropes’ compared to the ‘dry food ‘preserving. Furthermore, respondent gender was a significant variable in the preparedness measure of having a first aid kit. The statistical significance indicates that the final model is a significantly better fit as compared to the null model [chi-square (24) = 101.035, $p < 0.001$]. Pearson’s chi-square test indicates that the model is not a good fit over the data [chi-square (1560) = 1684.756, $p = 0.014$], whereas the Deviance chi-square indicates a good fit [chi-square (1560) = 987.282, $p = 1.00$] (Table 9).

4 Discussion About Adaptation

The multiple logistic regression results show the impacts of farmers’ age, gender, and total income on various adoption measures against changing climate and SLR. The variation in total income had a significantly positive effect on the choice of adopting ‘salinity-tolerant livelihood farming’, compared to shrimp or fish farming. Furthermore, the adaptive mechanisms of CC such as ‘climate justice’, ‘tree plantation’, ‘places for shelter’, ‘help of an NGO’, and ‘awareness and planning’ were significantly influenced by age. The gender of respondents had a significant influence in the support for discouraging the development of new shrimp farms, compared to building new dams. Additionally, age had a significant influence in adopting ‘alternative sources of income’ as measures against sea level rise. The adoption of ‘supporting houses with bamboo and rope’ to minimize the hazards of changing climate and SLR was significantly affected by the total income of respondents.

The interview revealed that the Upazila Chairman was inspired by the Shyamnagar Agro Technology Park and was planning to plant a rooftop garden with the cooperation of the Upazila Agriculture Office and various NGOs. The rooftop garden model has been adopted by many farmers and shows a great prospective for adaptation to changing climate.

In the three villages of Kalbari, Burigoalini and Arpangshiya, alternative salt-tolerant farming methods are being implemented with the support of non-governmental development organizations. The NGOs are distributing salt-tolerant seeds to 60 families. Another survey respondent, a resident of the Ishwaripur Union village, reported that he grows a salt-resistant Kharif rice variety; however, Kharif rice is not cultivated more widely due to lack of technical support. More farmers can benefit from this system; however technical support and access to inputs will be essential to its success as a widespread adaptation strategy (FGD).

Another case study was completed in the village of Durgabati, where a landless farmer, X (age 56) attended the non-governmental organization (NGO) Caritas training programme. Afterwards, he began growing pumpkins, sweet pumpkins, beans, shrimps, chichinga, rice squash, cucumbers, puishak, and barbati. The training programme taught respondent X to grow vegetables at a lower cost to help improve his financial situation. Although he lost his vegetables in a storm flood from river

Table 9 Multiple logistic regression model (MLRM) of covariates of people's perception/opinion for preparedness against hazards due to CC and SLR (*Source* Authors)

Parameter estimates

Preparedness against hazards due to CC and SLR	Independent Variables	B	Std. Error	Wald	Df	Sig	Exp (B)	95% Confidence Interval for Exp(B)	
								Lower bound	Upper bound
Moveable woven	Gender	−19.055	0.000		1		5.30E−09	5.30E−09	5.30E−09
	Age	0.007	0.018	0.128	1	0.72	1.007	0.971	1.044
	Total earning	0.000	0.000	1.189	1	0.276	1.000	1.000	1.000
Savings	Gender	−0.005	0.552	0.000	1	0.993	0.995	0.337	2.937
	Age	0.053	0.020	7.411	1	0.006	1.055	1.015	1.096
	Total earning	0.000	0.000	0.558	1	0.455	1.000	1.000	1.000
Fire wood	Gender	−0.180	0.400	0.202	1	0.653	0.836	0.382	1.829
	Age	−0.013	0.015	0.736	1	0.391	0.987	0.958	1.017
	Total earning	0.000	0.000	4.88	1	0.027	1.000	1.000	1.000
Supporting/tiding house with bamboo and rope	Gender	−19.121	0.000		1		4.97E−09	4.97E−09	4.97E−09
	Age	−0.007	0.016	0.179	1	0.672	0.993	0.962	1.025
	Total earning	0.000	0.000	4.561	1	0.033	1.000	1.000	1.000
Plinth rising homestead	Gender	1.012	0.610	2.755	1	0.097	2.751	0.833	9.086
	Age	0.013	0.022	0.364	1	0.546	1.013	0.971	1.057
	Total earning	0.000	0.000	1.752	1	0.186	1.000	1.000	1.000
First aid box	Gender	−1.660	0.793	4.377	1	0.036	0.19	0.04	0.9
	Age	−0.014	0.021	0.439	1	0.508	0.986	0.946	1.028
	Total earning	0.000	0.000	0.208	1	0.648	1.000	1.000	1.000

(continued)

Table 9 (continued)

Parameter estimates

Preparedness against hazards due to CC and SLR	Independent Variables	B	Std. Error	Wald	Df	Sig	Exp (B)	95% Confidence Interval for Exp(B)	
								Lower bound	Upper bound
Tree plantation surrounding the house	Gender	0.069	0.411	0.028	1	0.866	1.072	0.479	2.397
	Age	0.028	0.015	3.665	1	0.056	1.029	0.999	1.059
	Total earning	0.000	0.000	1.284	1	0.257	1.000	1.000	1.000
Other	Gender	−0.572	0.418	1.874	1	0.171	0.564	0.249	1.280
	Age	−0.010	0.015	0.443	1	0.506	0.990	0.960	1.020
	Total earning	0.000	0.000	11.678	1	0.001	1.000	1.000	1.000

a. The reference category is: dry food

Model fitting information

Model	Model fitting criteria	Likelihood ratio tests			Pseudo R-square
	−2 Log likelihood	Chi-Square	Df	Sig	(Cox and Snell)
Intercept only	1179.201				
Final	1078.166	101.035	24	0.000	0.272
Goodness-of-fit					
Pearson		1684.756	1560	0.014	
Deviance		987.282	1560	1.000	

erosion, his vegetables, which previously sold for 20 tk per kilogram, were now priced at 40–50 tk with the new crop.

In another case study, Y (age 48) lives with her fisherman husband in the village of East Durgabati. She has a saltwater pond at her house and learned how to farm shrimp and fish. Y also gained knowledge about market prices, growing various vegetables (spinach, pumpkins, gourds, beans, zucchinis, and cucumbers), the use of seeds, and planting trees (bananas). She found that planting 10–15 different types of vegetables produced 30–35 kg/day of vegetables. Afterwards, she received formal training and started a fish farming business from her pond. Currently, she works in a nursery and raises shrimp larvae. Her annual profit, including land loss, is between US $650 to $750.

Another case study conducted in Shyamnagar Upazila, where Chairman Bhabatosh Kumar Mandal reported a series of crops on the roof and near the Parishad Union building to compensate for the adverse effects of CC and SLR on agriculture. Approximately 61 varieties of fruit trees were grown in this area, including the emblematic myrobalan, apple, star-apple, guava, vedana, chalta (sour apple), jackfruit, kul, gab, kadbel (sour wood-apple), banana, and grapes. Apart from fruit trees, there were approximately 143 different types of flora, such as flowers, uncultivated plants, and medicinal plants. A pond in the vicinity also has an array of fish species.

Alternatives that could create a more resilient and climate-smart agricultural system include more complex gher farming (aquaculture) to allow for the growth of shrimp, fish and prawns; and floating vegetable gardens in flooded areas using water hyacinth covered with soil. Kangkong (water spinach) farming is often located near ponds and increased production could also help food shortages. The Sorjan farming technique is a type of pyramid cultivation where long beds are used for vegetables, and crops alternate in furrows or trenches; with this technique, immersion-tolerant plants are used for fish farming (Amin and Eagle 2016; Hossain et al. 2015). It is also possible to use the ‘hari’ method, in which the ‘gher’ farmers cultivate freshwater fish in ponds during the monsoon and subsequently expel the unused water on their expenses to cultivate boro paddy during droughts (FAO 2015). To address the challenges of changing climate, farmers from Pakhimara village have formed the Pakhimara Women’s Agricultural Organisation for Environmentally Friendly Integrated Farm Management (IFM). The IFM provides training programmes on farming and the use of organic pesticides. After attending a training session, X learned how to do a variety of activities in her farmhouse. 49.1% and 19.7% of household survey respondents indicated that NGOs and the government, respectively, had contributed to embankment renovations following the damages caused by cyclones and floods. In addition, 27.5% of the respondents agree that NGOs have implemented a tree planting programme to reduce river erosion. Furthermore, 20.9% of the respondents agree that the government has raised the issue of climate justice at the global level and has proposed new technologies for mitigation initiatives.

As for the negative impacts of the Farakka Barrage in agricultural production, the Bangladesh government is considering a Chinese proposal to dredge and dike the River Teesta in order to form a single manageable channel. Of the 315 kms of

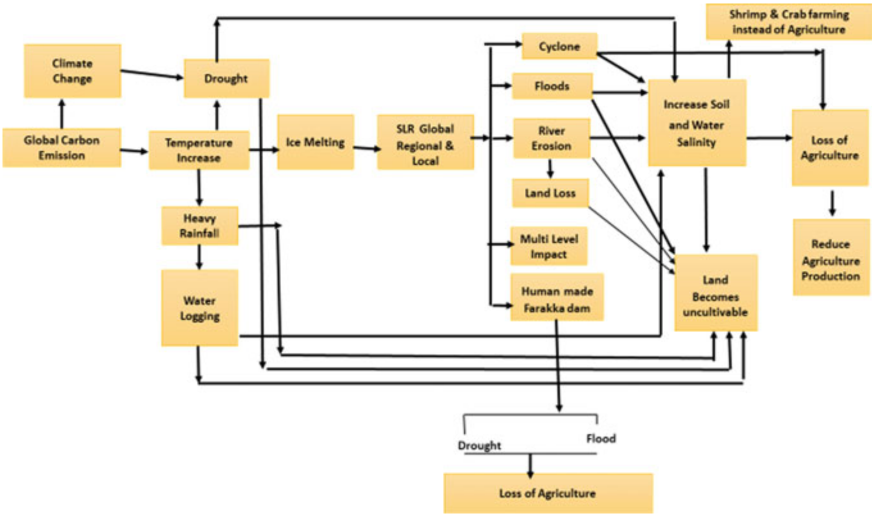


Fig. 8 Results of the vulnerability to changing climate and rising sea level (*Source* Authors)

rivers, approximately 113 kms are located in Bangladesh, reducing vulnerability and enhancing adaptation in the SWCRB (Roy 2020; Chakma 2021).

The results suggest complex interactions between the effects of changing climate and SLR and negative feedback loops consisting of adaptation that further cause the region to be increasingly vulnerable (Fig. 8).

Though farmers have innovated in several methods for adapting to their vulnerability to changing climate, they recognize that their efforts will not suffice in ameliorating the increasing adverse effects of changing climate and SLR.

5 Conclusions

Changing climate and SLR are already negatively impacting agricultural livelihoods in the south western coastal region of Bangladesh. Heavy rains, floods, droughts, erosion and salinity have an adverse effect on the financial resilience of households and their livelihoods. Salt intrusion into drinking water and soil also hinders crop production and adversely affects the health of population in proximity to the study area. River water salinity has also resulted in the loss of freshwater fishery resources. In addition, farmers have adopted various measures to fight the challenges of SLR and changing climate. The building of dams around agricultural land, harvesting rainwater, adequate drainage to eliminate prolonged waterlogging and saltwater ingress, controlling the creation of shrimp farms, cultivating salt-tolerant HYV crops, conserving rainwater in ponds in saline areas and using modern irrigation techniques are adaptive measures used by the farmers. In addition, rooftop gardening in saline areas, homestead gardening, Sorjan farming technique and floating cultivation, livestock farming, CSA in adaptive agricultural practices, etc. have been considered by coastal farmers to lessen the intensity of changing climate on coastal agriculture. Although the government and NGOs have implemented adaptive measures, they need to be more user-friendly. It can be observed from the results of the present study that the inhabitants of the SWCRB require more governmental support, such as training programmes, increased knowledge of the optimum usage of organic fertilizers and pesticides, innovative farming techniques, including the adoption of smart agricultural climate practices. If further investments are not made, as exposure to climate change impacts increases, farmers' adaptive capacity is likely to decrease causing an increase in the overall vulnerability of SWCRB. Besides, this research presented highlights the innovative nature of farmers in SWCRB in response to changing climate, yet concludes that efforts are insufficient for vulnerable populations. Future interventions should be designed to take into account the diverse needs of vulnerable populations, considering age, gender, and economic status to design appropriate measures in the future. Moreover, this research supports the need to ground adaptation policies in bottom-up approaches, taking due account of local perceptions and strategies, in order to consistently reduce agricultural vulnerability in the SWCRB over the long term.

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A Proposed Methodology to Map Soil Moisture in Support of Farm-Level Decision Making Under Changing Climatic Conditions

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1 Introduction

Soil moisture (SM) is vital for crop production because it is one the most important links between precipitation and crop growth (El Hajj et al. 2016; Gao et al. 2021). However, this information is rarely available for agricultural fields in data-scarce areas due to limited deployment of field equipment (Filion et al. 2016; Wang et al. 2021). Furthermore, the use of field equipment is resource intensive and incapable of providing timely information for large-scale applications (Mohanty et al. 2017; Sharma et al. 2021). In-situ SM data are also problematic because their zone-based collection in different units makes it difficult to integrate information (Brocca et al. 2017). The lack of spatially detailed information has compelled many practitioners and researchers to rely on subjective estimates that are extrapolated from coarse resolution datasets. This limitation can be addressed by using remote sensed data which, are becoming increasingly available. Remote sensing (RS) provides detailed (~0–5 cm) SM monitoring capabilities (Sadeghi et al. 2017). Petropoulos et al. (2015) provide several remote sensing-based techniques that are based on the high correlations between SM content and soil optical reflection, thermal emission and, microwave backscatter (Zhang and Zhou 2016). At small spatial scales, optical

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satellite observations have tremendous capabilities to address the lack of soil moisture information (SMI) because of their high spatial (centimetre to metre) resolutions (Babaeian et al. 2018; Zhang et al. 2021).

Several techniques that use these data are now available. An example is the optical trapezoid model developed by Sadeghi et al. (2017) based on the established physical linear relationships between SM and shortwave infrared (SWIR) transformed reflectance. Although the SWIR optical signal is extremely useful because of its sensitivity to SM variations (Sadeghi et al. 2017), several RS platforms like SPOT and others do not provide SWIR observations. Effective use of the available datasets is also constrained by lack of appropriate image-based SM mapping techniques. These limitations justify a need in developing countries for robust RS-based SM estimation models that use the Red-Near Infrared (Red-NIR) bands of the electromagnetic spectrum (Foroughi et al. 2020).

Efforts to develop such models have so far yielded techniques that can be used for the mapping of SM at multiple temporal and spatial scales (Zhang and Zhou 2016; Edokossi et al. 2020). Some of these techniques are based on the relationships between SM and RS land surface parameters (Petropoulos et al. 2015; Kashyap and Kumar 2021). Other examples include the evapotranspiration-linked water deficit index developed by Moran et al. (1994) and the temperature vegetation dryness index (TVDI) developed by Sandholt et al. (2002). The TVDI is one of the recent contributions worth considering because of its minimal reliance on surface temperatures and normalized difference vegetation indexes (NDVIs), which are easily retrievable from remotely sensed imagery.

An additional example is the NIR-based perpendicular drought index (PDI), which is closely correlated with average SM at depths of 0–20 cm (Ghulam et al. 2007a, 2007b). Unfortunately, however, it is not widely used because it is not able to handle the effects of vegetation. Ghulam et al. (2007a) and Amani et al. (2016) attempted to address this shortcoming by developing the modified perpendicular drought index (MPDI) and the triangle SM index which are highly correlated with SM at a depth of ~5 cm. Amani et al. (2017) followed this up by converting the NIR-Red spectral space to the SM perpendicular vegetation index (SM-PVI). Efforts to improve the performance of some of these models include use of the commonly available reflectance of the Red and NIR by Foroughi et al. (2020).

The effective use of these models is however constrained by (1) the prohibitive costs of high resolution images, (2) their inability to provide the optimum spatial coverages required for planning purposes and (3) limited accessibility upon request (Babaeian et al. 2019). These shortcomings justify why South Africa needs to focus on the freely available medium scale (6–10 m) Sentinel-2 and SPOT images which can be used as alternatives for reliable SM estimation (Hlatshwayo et al. 2019; Maponya et al. 2020). Although the data provided by these satellites are readily accessible, their usefulness has not been fully exploited. This drawback requires the scientific community to explore techniques that broaden our capabilities to use these and other datasets that are becoming increasingly available (Chari et al. 2021a). The majority of South Africa's farmers who are largely dependent on rain-fed crop production, stand to benefit from innovative use of these resources (Myeni et al. 2019). These datasets are also vital for drought early warning and the formulation and implementation of data-driven management strategies (Mladenova et al. 2020). The need for this remote-sensing based information is evidenced by the countrywide lack of adequate SM monitoring stations, with the Eastern Cape Province for example, having only one station (Myeni et al. 2019). In these areas, SM is also extremely important because it a reliable indicator of the functioning of wide-ranging ecosystem processes and the natural balance between water uptake and utilization.

In this chapter, we test the performance of a SM monitoring index (SMMI) derived from the freely available SPOT-6 imagery. This is done by hypothesizing that the SMMI is a reliable estimator of SM. The study attempts to identify the major factors that influence this index's ability to estimate SM and to determine whether seasonal timing affects its performance for farm-level decision making. The method provided here is adaptable and capable of producing dependable SMI in support of farm-level decision making.

2 Materials and Methods

2.1 Study Area

The study area comprises eight wards (wards 2, 5, 6, 10, 11, 12, 14 and 16) in South Africa's Raymond Mhlaba Local Municipality (RMLM). These wards were selected because they contain most of this municipality's arable land (Fig. 1), covering an estimated 529 km^2, which is dominated by marginal soils with variable SM retention capacities.

RMLM is the largest of Amathole District Municipality's six municipalities (Local Government Handbook 2016). The area has a dispersed settlement pattern that is largely determined by the availability of arable land, most of which is marginally productive and unsuitable for subsistence farming. The average midday temperatures range from 19.3 to 28.3 °C (www.statssa.gov.za). Annual rainfall averages 600 mm, with most of this amount occurring in the autumn season, and the minimum and maximum amounts approximating 7 mm and 66 mm in July and March respectively (Chari et al. 2021b). This rainfall regime poses serious challenges on the abilities of local communities to adapt to climate change-induced food and water scarcities. The adaptive capacities of these communities are further undermined by reoccurring droughts and overwhelming reliance on natural resources and subsistence farming (Chari 2022).

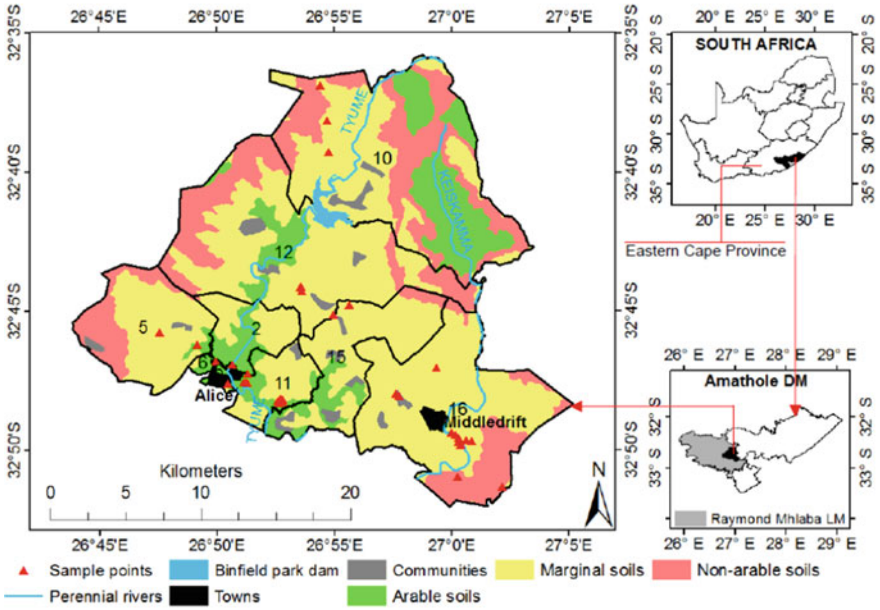

Fig. 1 Location of the study area in South Africa. *Source* Chari (2022)

2.2 *Image Compilation and Preprocessing*

2.2.1 Image Compilation and Preprocessing

The images that were used include SPOT-6 coverages of 2014, 2015, 2016 and 2017 (Table 1).

These images were provided free of charge and georeferenced from source at 6 m spatial resolutions in the Blue, Green and Red spectral bands that are ideal for SM mapping (https://eos.com/spot-6-and-7/).

Table 1 Acquisition dates of the images that were used

Year	Month
2017	18 October
2016	08 November
2015	05 September
2014	11 April

Source South African National Space Agency (SANSA)

2.2.2 Image Pre-processing

The images were atmospherically corrected by using the FLAASH model provided in ENVI (2009) following the procedure suggested by Benabdelouahab et al. (2015). This procedure involves radiometric rescaling by executing Eq. 1, where L_λ is the top-of-atmosphere spectral radiance and DN is the digital number of the original image.

$$L_\lambda = \frac{DN}{Gains} + Bias \tag{1}$$

Radiometric rescaling (R-R) was preferred because of its recognized accuracy in the atmospheric correction of SPOT images (Guo and Zeng 2012; Siregar et al. 2018). The FLAASH model executes an aerosol and mean value retrieval processing which eliminates the effects of atmospheric disturbances by using the dark pixel reflectance ratio to generate accurate reflectances of land surface features (Siregar et al. 2018). R-R was also used because it reduces atmospheric image contamination by enhancing the information provided in fundamental pixel primitives (Hamandawana et al. 2005; ENVI 2009; Siregar et al. 2018).

2.2.3 In-Situ Soil Moisture Measurements

The data were collected on fairly flat surfaces at depths of 0–5 cm from 36 randomly selected sites (Fig. 1). The collection was carried out in October 2017 to enhance close temporal correspondence with the acquisition of the SPOT image of 18 October 2017 (Table 1). This arrangement provided a SM map-output whose accuracy was tested by using in-situ soil moisture measurements of the same period that were determined gravimetrically at the laboratory following the methods described by Day and Black (1965).

Assumptions: The underlying assumptions were that (1) in-situ SM collected between 4–7 October is a close estimate of satellite-based SM measurements on 18 October 2017, (2) if the methodology used to produce the map output of 18 October 2017 proved to be reliable based on the above-described accuracy assessment procedure, then, the same method could be used to reliably classify other images where temporally corresponding field measurements were not available, (3) in all localities within our study area, there was no rain in the dry summer days before 18 October 2017 as evidenced by rainfall records from weather stations in this area, (4) evaporative differences in SM over the 11 days between 7 October 2017 and 18 October 2017 were bound to be minimal under near stable daily temperatures during this period. The reasoning behind these assumptions explains why (1) the SM data that was collected between 4 and 7 October 2017 was used as a close correlate (ground truthing) of the satellite-based moisture estimates of 18 October 2017, and (2) the image-based map output of 18 October 2017 was validated with the ground truth of 4–7 October 2017.

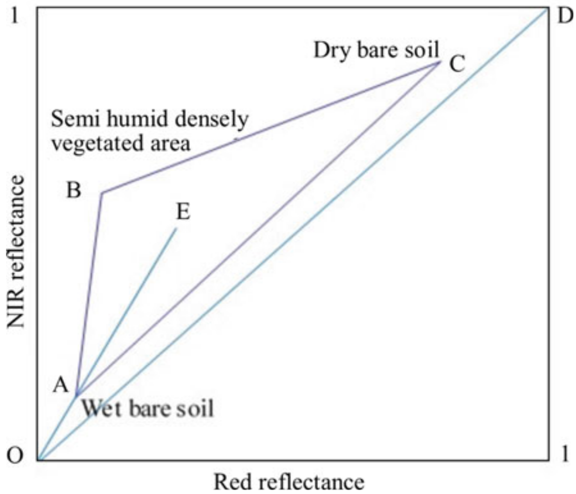

Fig. 2 Distributions of SMMIs in the NIR-Red band spectral space. *Source* Adapted from Liu et al. (2017)

2.2.4 Soil Moisture Monitoring Indexes (SMMIs)

Figure 2 shows distributions SMMIs in the NIR and red band spectral space.

As shown in Fig. 2, there is a decrease in SM from point A in the wet bare soil to point B the semi-humid densely vegetated area and to point C the dry bare soil. The distance of any point from points E and O in the NIR-Red space explains the changes in SM (Liu et al. 2017). When point E is at point A, |OE| is at its smallest and the SM estimate at its highest value. When point E is at point C, |OE| is the largest, and the SM is the smallest so regions close to point O are either water bodies or humid areas. The regions far from point O are either relatively dry or with low vegetation cover. These relationships indicate that the SMMI, is reliably capable of estimating SM in the NIR-Red spectral space.

The following equation is used to calculate the SMMI.

$$SMMI = \frac{|OE|}{|OD|} = \sqrt{ri^2 + rj^2}/\sqrt{2} \tag{2}$$

In this equation, r_i and r_j are reflectances of the NIR and Red bands respectively. SMMIs vary between 0 and 1, with low values indicating high SM content and vice-versa.

2.2.5 Validation

In order to test the hypothesis that SMMI is reliable in estimating SM at farm-level, regression analysis and Analysis of Variance (ANOVA) were performed by regressing and correlating in-situ soil moisture (ISM) percent values on and with SMMI.

3 Results and Analysis

Results are presented in the form of, (a) statistics from ANOVA and regression analysis of in-situ SM vs SMMI (Table 2), (b) a graph that shows the correlations between ISM and SMMI (Fig. 3) and, (c) thematic maps that show spatial distributions of SM that were mapped from the SPOT-6 images of 2014, 2015, 2016 and 2017 (Fig. 4).

The results revealed negative correlation ($y = -20{,}588x + 7{,}2534$; $R^2 = \sim 0.4121$) between the SMMI and SM (Table 2 and Fig. 3). The implication of this observation is that we do not reject the hypothesis that SMMI is a reliable estimator

Table 2 Product statistics from ANOVA and Regression Analysis of ISM vs SMMI

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	3,823,570,557	3,823,571	2,382,985	244,478 E−05
Residual	34	5,455,401,665	1,60,453		
Total	35	9,278,972,222			
	Coefficients	Standard error	t Stat	P-value	
Intercept	725,336,1935	0,846,282,001	8,570,857	5,18E−10	
SMMI	−205,881,298	4,217,511,259	−4,88,158	2,44E−05	
Regression analysis					
Multiple R	0,641,925,484				
R Square	0,412,068,327				
Adjusted R square	0,394,776,219				
Standard error	1,266,700,399				

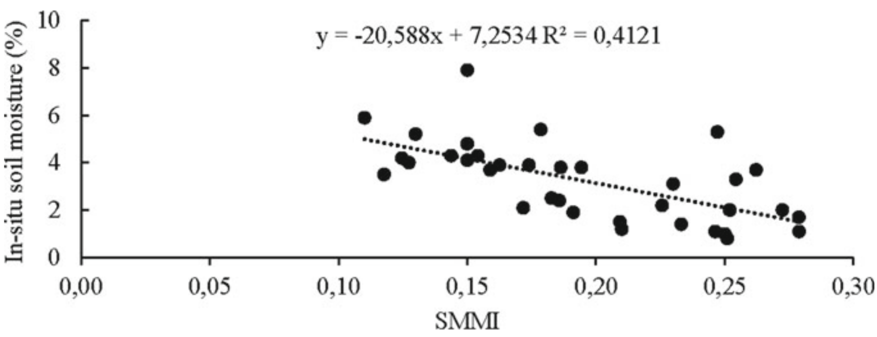

Fig. 3 Correlation between the SMMI and in situ SM (n = 36)

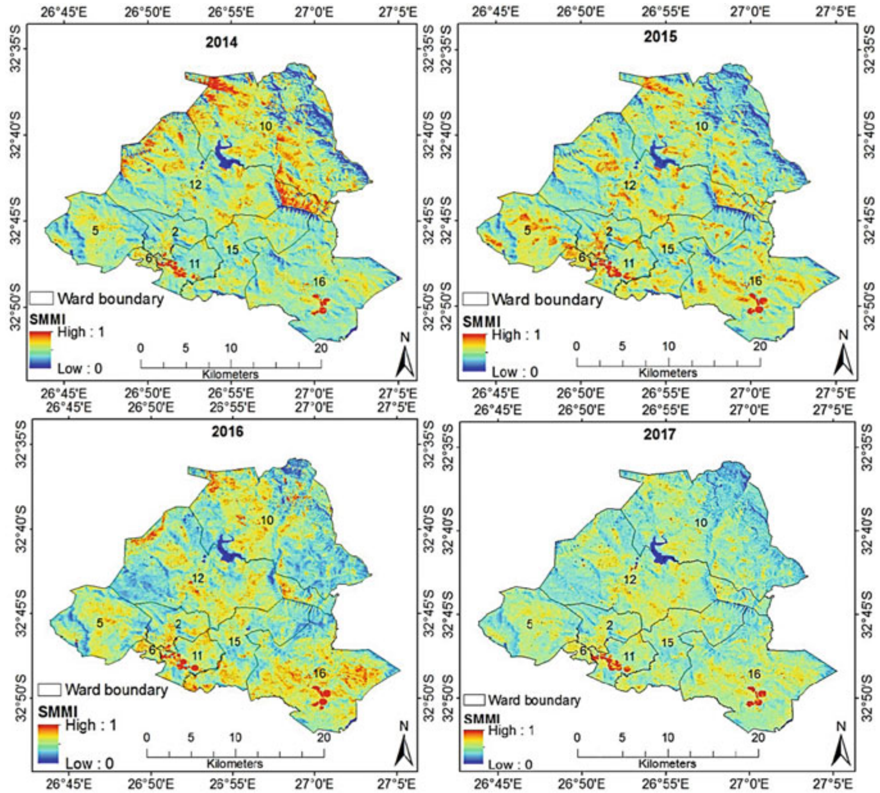

Fig. 4 Soil moisture distributions from SMMI for years 2014, 2015, 2016 and 2017

of SM. This finding is consistent with observations by Yue et al. (2020) and by Liu et al. (2017) who also observed negative correlations between the SMMI and SM.

4 Discussion

The findings of our study confirmed the hypothesis that SMMI is a reliable estimator of SM. This finding is important because it demonstrates that this index can be used to provide useful information at levels of detail and accuracy that are commensurate with the requirements of farmers and practitioners interested in securitizing food production. One of this investigation's major insights is that SMMI performs well when the density of landcover is low. For example, the area covered by Binfield Dam (Fig. 4) has the lowest SMMI values. This finding is reflected in Fig. 2, which shows wet bare soil as the closest cover type to point O in the NIR-Red band spectral space.

This finding is important because it directs attention to algorithms that are reliably capable of yielding usable SM estimations.

This inter-band discrimination capability is due to the fact that signatures received by the sensor are dependent on the spectral characteristics of different vegetation types. This explains why soils under irrigated pastureland respond differently from soils under natural grassland due to the species-related influences of vegetation on emitted SM reflectance. For example, soils in irrigated pastureland reflect differently than natural grazing land because of the extraneous influence of their superficially cultured greener foliage. For instance, in Fig. 4, SMMI did not perform well in very dense landcover, which is the pivot-irrigated pastureland in Wards 11 and 16 where lucerne is grown. This implies that NDVI maps can be used in conjunction with SMMI in order to establish areas with dense vegetation cover.

The implication of this relationship is that accurate SM estimates are obtained when the soil is bare as happens when land is cultivated. We therefore urge researchers to use images that were acquired under low soil cover conditions in order to minimize the effects of vegetation on the SM retrieval capabilities of remote sensed data.

We further recommend this consideration because, apart from cost-effectively delivering the required results, the SMMI can accommodate the errors that often undermine the SM estimation capabilities of remotely sensed data (Sayão et al. 2018). The usefulness of RS data needs to be fully exploited because of its immense potentials to cost-effectively provide SMI compared to conventional measurement techniques. RS of SM offers the additional advantage that it provides datasets that are easily updatable and shareable through online platforms (Fang and Lakshmi 2014).

Research has shown that RS offers a cost-effective means to timely provide SMI at levels of detail that meet the requirements of rain-fed crop production by resource-poor farmers in data-scarce areas where this information is badly needed but difficult to provide. Because of the overwhelming dependence of most rural communities on rain-fed agriculture, current and future climatic variability threaten the ability of these communities to meet their food requirements through the adoption of climate-friendly crop production practices. In view of the persistent deterioration of climatic conditions in South Africa, techniques that can be used to cost-effectively provide SMI are critical. There is therefore, pressing need to continue investing in the formulation of affordable techniques that can be used to provide timely SMI at different spatial scales. As shown in this study, there are a lot of untapped opportunities that need to be explored and exploited in order to enhance better use of the wide-ranging RS datasets that are becoming increasingly available.

5 Conclusion

This chapter presented a cost-effective and replicable approach to estimate SM by using the readily accessible SPOT-6 images. The technique that was used in this investigation was able to discriminate SM distributions at levels of detail and accuracy that are commensurate with the requirements of most stakeholders interested in enhancing the sustainability of rain-fed crop production under changing climatic conditions. Because SMMI performs well when vegetation cover is low, researchers need to consider seasonal timing in the sampling of RS datasets used to estimate SM. Overall, the insights provided here demonstrate that RS data have immense potentials to cost-effectively provide usable SMI. Exploring different techniques to maximize the use of freely accessible remotely sensed images can support agriculture in South Africa and other developing countries by providing SM information in data-scarce areas where it is badly needed but difficult to provide.

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The Role of Integrated Organic Cycle Farming in Tropical Agroforestry Systems for Sustainable Food Production

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1 Introduction

Tropical ecosystems are rich in natural resources, biodiversity, cultural diversity, and natural beauty. In tropical ecosystems, biological, environmental, and social-cultural productivity are the highest globally, but their economic value is relatively low. Despite covering just 3% of the planet's total land area, Southeast Asia's tropical rainforests are home to over 20% of all recognized plants, animal, and marine organisms, many of which are unique to this part of the world (Keong 2015). Indonesia is the most biologically diverse among the three mega-diverse countries in Southeast Asia and the second most diverse territory after Brazil. After the Congo and Brazil, it also includes the world's third-largest forested region. Its rainforests are home to 10% of the world's flowering plants, 12% of the world's mammal species, 16% of all reptile and amphibian species, and 17% of the world's bird species (Keong 2015). Globally, Indonesia has the most mammalian species (720), with 36% of them being endemic to the country, and the most swallowtail butterflies (121 species with 44% classified as endemic) there are a total of 1.900 species of butterflies (Darajati et al. 2016).

Indonesia's biodiversity has been exploited in some areas, however some of its potential has yet to be identified. Essentially, while biodiverse areas have some potential to regenerate, this capacity is minimal. Furthermore, the health of biodiverse areas

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is highly dependent on human treatment given that they are required for life and may also be used as a resource for production. Therefore, the direct use of biodiversity entails risks. In this situation, the needs of different sectors within the government, society, and the private sector are not always aligned. Therefore, many factors influence the future of Indonesia's biodiversity and multiple challenges must be faced in the overall national development process, especially given the large population that demands the availability of various basic needs (Triyono 2013).

The development pathways in several tropical countries are still traditional and based solely on exploiting natural resources; thus, they have relatively low food security and sovereignty. According to Jorgenson and Dietz (2015), the present economic trajectories (i.e., those dependent on natural resources) are risky for generations to come because they lead to the degradation of numerous natural resources and environmental services. Indonesia's high deforestation rate clearly indicates the degradation of natural resources and environmental services. Deforestation in Indonesia began in the late 1960s at the beginning of the new era, with the enactment of the foreign direct investment law, which kick-started the exploitation of the natural forests (Ardhana 2016). Massive deforestation and forest fires have caused biodiversity loss from the Sunda region to the Sahul region, causing the extinction of several species (Ardhana 2016).

According to Rusdiana and Maesya (2017), economic growth in Indonesia can, as people's incomes rise, tangibly impact dietary demands. Indonesia has diverse natural resource capacities and numerous opportunities to achieve sustainable food self-sufficiency. Natural resources and biodiversity can be exploited, given the rapid advancement of various technologies, to produce, for example, non-rice carbohydrate, protein, and micro-nutrient sources in each area. Advances in production, post-harvest processing, distribution, and marketing could increase food production capability, productivity, and quality, thus increasing the benefits of the food agribusiness and meeting national food security goals.

Waldron et al. (2017) argues that while conventional farming is essential for global food security, it has caused significant environmental and social harm. There is a widely held view that we need a farming system that can "multi-functionally" boost crop yields while strengthening social and environmental outcomes aligned to sustainable development goals (SDGs); agroforestry is such a system. Agroforestry, however, must also become more resilient to various risks, such as changing climate, soil depletion, market uncertainty, reducing sustainability, and worsening hunger (Garrity et al. 2010). Both are units of compacted proceeds systems, namely the Agroforestry systems (AFS) is a mix-planting systems of trees and crops, or the sylvo-pastural systems (SPS) is a mix land management systems of trees, pastures and livestock, can increase crop resilience, especially among the most vulnerable food producers (Montagnini and Metzel 2017), and can also impules short- and long- term productivity (Santos et al. 2019). These systems not only provide benefits for improving the biodiversity of nature but also for improving the social and economic of farmers (Reyes et al. 2005). The management of AFS by many indigenous communities includes leftover and ash management, recycling of nutrient, and conservation- preservation of high species diversity, all of which contribute to the long-term viability of the agro-ecosystem (Montagnini and Metzel 2017). Furthermore, Jamnadass et al. (2013) argued that agroforestry can help protect the food supply by (i) directly supplying tree foods, such as fruits and green leafy vegetables, and can promote the production of staple crops; (ii) increasing farmers' income by selling surplus produce; (iii) providing cooking fuel; and (iv) supporting various ecosystem services, such as pollination. These benefits also contribute to improved nutrition and probiotic ecosystems.

The integrated bio-cycle approach has become the best alternative in a productive natural resource management system for sustainable conservation in tropical ecosystems (Agus 2018; Agus et al. 2020). This nature-based cultivation system can produce food, feed, shelter, energy, medicine, water, oxygen, and tourism in a single landscaped ecological management system (Agus et al. 2021). This chapter describes the role of AFS in food security and sovereignty in Indonesia, with nature-oriented land management through an integrated bio-cycle management system.

2 Material and Methods

This analysis used a descriptive method based on secondary data, a problem-solving approach that involves describing the situation of the research object based on the data obtained (Nawawi 2013). Secondary research data including theory, precedent, and industry norms were collected from publications, books, journals. These data on integrated organic cycle farming, AFS, and challenges and concepts of sustainable food sovereignty are described here using thematic study methods. A qualitative analysis of the current site data identifies answers to similar problems. Data integrity is ensured by data triangulation, a data credibility test that involves evaluation and comparison of data from many sources using the same procedural approach (Sugiyono 2018; Creswell and Creswell 2017).

3 Results and Discussion

3.1 Sustainable Agriculture Development

Agriculture growth is a component of the idea of long-term development. Many concepts of sustainable development have arisen, but the Bruntland Commission's report is widely agreed by the international community, meaning development that satisfies current requirements without decreasing or destroying future generations' ability to satisfy their daily needs (United Nations 1987). Economic, environmental, and social sustainability are the three core dimensions of sustainable development. Economic sustainability is characterized as development capable of producing products and services continuously to maintain agricultural and industrial production.

Environmental sustainability refers to production that preserves and avoids misuse of natural resources (biodiversity, air space, and other ecosystem functions). A structure capable of achieving equity and delivering social services, such as health, education, gender equality, and political transparency, is referred to as social sustainability (Rivai and Anugrah 2011). Sustainable development is described as progress that improves the current generation's well-being without jeopardizing the interests of future generations. It reveals intergenerational equity and ensures that well-being does not degrade with time (Santos et al. 2019; Mansour et al. 2020).

If environmental conservation is ensured, agricultural production can be sustainable. Otherwise, deforestation or gradual soil depletion and environmental degradation, in general, render economic growth impossible. In this context, sustainable agriculture development refers to a new approach to agricultural development that enables agriculture to provide economic and social benefits to current generations while not jeopardizing future generations' ability to meet proper agricultural demands or jeopardizing the fundamental ecological process. This definition stresses that any major deterioration or contamination of the ecosystem and ecological processes caused by agriculture cannot be sustained in the long run. According to Santos et al. (2019), three requirements must be met for sustainable agriculture development: (1) Eco-capacity conservation protects the ecosystem's ability to function in the face of pollution. (2) Effective use of environmental, human, material, and energy resources. (3) The assurance of an equal distribution of population, agricultural production products, and environmental degradation-related loads.

Sustainable agriculture growth refers to management of agricultural commodity production to meet human needs within the framework of sustainable management of living natural resources by considering the improvement of environmental quality and the preservation of natural resources (Govind and Stigter 2010). The term "sustainability" was used in this context to refer to the economic viability of using fewer resources, mitigating environmental harm, and maintaining biological cycles in an agricultural society. Usefulness, sustainability, autonomy, cohesion, compactness, self-sufficiency, transparency, equal quality, local knowledge, environmental functions sustainability, and state security are all variables in establishing sustainable agriculture systems (Anonymous 2019).

Sustainable agriculture systems in agroecosystems are agricultural management paradigms that involve three aspects of economic, ecological, and social (D'Amato et al. 2019). Sustainable agriculture practitioners strive to include three key goals into their work: a sustainable climate, economic profitability, and social and economic justice (Adnan et al. 2019). As an effect, present and future generations can reap the advantages. It is understanding the many ecological consequences of sustainable agriculture, however, needs knowledge of essential stakeholders such as farmers, government, policymakers, researchers, or mentors (Govind and Stigter 2010). In economic terms, sustainable development means that a development activity must promote economic growth while maximizing resources and investment. Sustainable means that practices must preserve the ecosystem's integrity, the environment's carrying capacity, and natural resources, including biodiversity, in an ecological sense. Finally, sustainable development can result in equal outcomes, social mobility, and structural development in the social context.

Agroecological research is used to treat agro-ecosystems sustainably. Agroecology is a multidisciplinary study of biological, environmental, and managerial variables in agricultural systems that employ ecological science to develop and manage sustainable Agro-ecosystems (Gliessman 2018). It may also be featured as a strategy for developing agro-ecosystems that sustain agricultural output, agricultural communities, and ecological health by integrating environmental and socioeconomic variables (Gliessman 1997). It emerged as a study topic in the 1980s, spanning a wide range of perspectives and efforts to construct integrated concepts and technique (Rickerl and Francis 2004). Ecological ecosystems highlight organisms' interactions with their physical surrounds, as well as the transmission of energy and material via linked biophysical systems (Chapin et al. 2002). Furthermore, combining ecological and agricultural research seeks to enhance agricultural productivity from an environmental standpoint (Gliessman 2007).

Various combinations, rotations, polycultures, agroforestry, crop-livestock integration, integrated bio-cycle farming system, and landscape (hedgerows, corridors) can all contribute to long-term agriculture productivity (Agus 2013; Agus et al. 2019). Various models of farming practices will give alternative for field development (Altieri et al. 2017). Agroecosystems can be realized using a variety of several agroecological ideas. There is, for example, (1) continuing to improve the biomass cycle across organic matter decomposition and nutrient cycles; (2) the act of improving the population balance of natural predators in pest control; (3) increasing the cycle of soil microorganisms by organic composted material management; (4) managing cycles of the energy, water, and nutrition; and (5) utilization of various typhoons (Altieri et al. 2017; Phelan 2009; Agus 2018; Agus et al. 2019).

It has proposed agroforestry as a low-cost technique that balances production, biodiversity conservation, and socioeconomic concerns. Agroforestry programs protect biodiversity and provide environmental services (Abbas et al. 2017; Santos et al. 2019). Small-scale agroforestry is often viewed as a mechanism that ensures local or indigenous peoples' survival without external inputs (Scherr 2004; Soto Pinto et al. 2010). One of the most prominent criticism levelled towards agroforestry is that it has a minor effect on socioeconomic position (Alavapati et al. 2004; Franzel et al. 2004). However, several instances from throughout the world show that value-added agroforestry products and efficient market development may assist smallholders in improving their lives (Dawson et al. 2014; Scherr 2004; Bennett and Franzel 2009).

According to Montagnini and Metzel (2017), in the Sustainable Development Goals (SDGs) context, implementing agroforestry can address and strengthen the achievement of several goals simultaneously such as 2nd SDG on zero hunger, 5th SDG on gender equality, 6th SDG on clean water, 7th SDG on accessible and clean energy, 10th SDG on reducing inequality within and across countries, 13th SDG on climate action, and 15th SDG 15 on sustainable forestry and restoration. However, because the SDGs are interconnected, agroforestry enable them to reach an even larger set of objectives than seems at first glance, including 1st SDG on poverty and 3rd SDG on excellent health and well-being. Meanwhile, forest may help in protecting the environment by storing freshwater, minimizing floods, and recovering infertile soils. However, clearing forests would come at a high price regarding environmental consequences, such as habitat loss and greenhouse gas emissions.

3.2 Agroforestry for Sustainable Food Security

Food is one of the most fundamental human needs. Many countries, including Indonesia, are trying to achieve food sovereignty and food security for their people through planning and implementing strategies based on regulations incorporating UN SDGs (Pemerintah Republik Indonesia 2012). In 2020, the Indonesian government's national priority agenda included food security based on food estate areas and the provision of "forest areas for food security" (KHKP) (Menteri Lingkungan Hidup dan Kehutanan 2020; Pemerintah Republik Indonesia 2012). This policy is controversial, with some presumptive narratives, because several past food estate programs have failed. The paradox is that the food estate plan is not actually for food security but it simply supports large-scale agribusiness expansion while the welfare of local farmers is neglected. The decisive role of large corporations in the food estate program raises concerns about environmental damage, increased loss of tropical forests, and triggered socio-economic losses (Dwiguna and Munandar 2020; Kamin and Altamaha 2019). Despite this controversy, most people still hope to realize the food security program, as released by the Indonesian government, to maintain national food sovereignty after improving and strengthening the concept in multiple aspects (Dwiguna and Munandar 2020; Nasution and Bangun 2020; Wuryandani et al. 2015).

However, the Indonesian government, through the Ministry of Environment and Forestry (KLHK), states that the provision of KHKP area, which is regulated by the KLHK Minister under Regulation P.24/Menlhk/Setjen/Kum.1/10/2020, is carried out through an environmental assessment strategy based on the principles and regulations of sustainable development (PPID KLHK 2020a). In addition, the KLHK stated that it would not change the status and function of protected and production forest areas to include non-forest functions even if designated as forest area for food estate development. Meanwhile, the products of food estates in forest areas are not limited to crops and paddy rice, but include multiple other food and nutritional commodities from the forestry, fishery, and farm parts of an estate (PPID KLHK 2020b). The concept to be developed is a multipurpose and sustainable forest landscape mosaic coupled with forest restoration efforts.

In addition, the forestry sector program contributes to food security not only through the KHKP, which has an area of several hundred thousand hectares, but also through the Social Forestry program, under which 12.7 million hectares of forested land will be targeted for use and management by local communities. Community and business development are both included in the program (Kementerian Lingkungan Hidup dan Kehutanan 2020). This corrective program seeks to redirect Indonesia's forest management policies for generate concrete actions leading to the sustainability of Indonesia's forests and an equitable distribution of community welfare. The program therefore has great potential to support Indonesia's food security.

Management and utilization of forests for food security, through the Social Forestry program, must follow the principles of sustainable forest resource ecosystem management in order to maintain the quality of Indonesia's tropical forests. AFS can be used to manage forest land for food supply and ecosystem sustainability (Widianto et al. 2003). The issue of food supply overlaps with issues of sustainable forest ecosystem services, which include increasing the multi-productivity of land, conservation of soil and water, maintenance of nutrient cycles, maintenance of the carbon cycle, and socio-cultural services (Waldron et al. 2017; Nair 1993). The forest ecosystems continue to support biodiversity and environmental services while simultaneously producing wood products and food and nutritional resources. AFS can be implemented on state forest land or private land to improve community welfare and save tropical forests by optimizing land use (Mayrowani and Ashari 2016; Sumanto 2009; Budiadi 2005). Therefore, AFS can be an agricultural extensification service, while remaining conducive to tropical forest ecosystems.

In Indonesia, agroforestry has developed theoretically and practically through traditional and modern land management systems with a combination of simple and complex components (Hairiah et al. 2003). Various models, technologies, and AFS innovations for food security combine silvicultural techniques with other methods: with agricultural techniques (agroforestry), husbandry techniques (silvo-pastoral), fishery techniques (silvo-fishery), or a combination (Nair 1993). However, consolidation and optimization are still necessary when developing tropical forest sites.

Research on the use of Indonesian mega-biodiversity, in the AFS context, as a diverse source of food, nutrition, and medicine needs to be prioritized (Wulandari et al. 2019). There is substantial potential for the domestication of flora and fauna in tropical forests of Indonesia, such as various forest fruits, tubers, fungi, and animals (Wisnubroto 2020; Darajati et al. 2016). The diverse plant species (including trees) and wildlife in the forest are a food production and nutrient source that can directly support food security (Andriyana 2021). Meanwhile, forests have an indirect but essential role of in food security as a habitat for certain insects and birds that are key pollinators for sustaining agricultural yields (Andriyana 2021; Susilawati et al. 2018).

3.3 Integrated Bio-Cycle in Agroforestry

Integrated bio-cycles in agroforestry cannot be separated from fertilizer and soil nutrients. Agus (2018) describes the Integrated Bio-cycle System (IBS) as a closed ecological system that must consider the management of land resources, biological resources, and environmental aspects. The management of land resources with biological resources is critical to the development of integrated agricultural systems, such as agroforestry.

Soil is a critical land resource factor (Agus 2018). Soil health is essential for plants to grow and develop properly. AFS are expected to improve soil health because of their effect on local biophysical conditions (Pardon et al. 2017) increased biodiversity through plant heterogeneity; planted trees, crops, and grasses; and through livestock (Marsden et al. 2019; Montagnini 2017; Shin et al. 2020). Based on the research of Santos (37), AFS can have 45% higher biodiversity than conventional agriculture.

According to Stefano and Jacobson (2018) and Abbas et al. (2017), AFS can also increase the absorption of atmospheric carbon dioxide through plant networks and the soil surface, thus playing a role in climate change mitigation. Stefano and Jacobson (2018) found that conversion from agriculture, pasture, and untreated land to agroforestry may increase soil organic carbon by 40, 10, and 25%, respectively, at soil depths of 0–30 cm. Meanwhile, according to Pardon et al. (2017) that various plants species' litter and rainwater provide additional soil organic carbon and soil nutrients such as nitrogen, phosphate, kalium, magnesium, and natrium in agroforestry systems.

Litter produced in AFS by trees and crops increases the availability of organic matter, which is then decomposed by soil fauna, making it beneficial for plant growth, producing additional organic matter. Therefore, there is a biological cycle in the agroforestry system. Ingham (2021) separated soil organic matter into four categories: live organisms (<5%), fresh residues (<10%), stable organic matter or humus (33–50%), and decomposing organic matter or active fraction (33–50%).

Soil fauna contributes to organic matter decomposition and nutrient cycling, as well as improving the physical and chemical qualities of soil (Dollinger and Jose 2018). Soil fauna can be used as a bioindicator of soil fertility (Fusaro et al. 2018; Ertiban 2019). Petit-aldana et al. (2019) also stated that the process of litter decomposition (leaching, fragmentation, ingestion, waste excretion, and changes in physical and chemical structure) in agroforestry plays a significant role as a source of natural fertilizers within the soil nutrient cycle, which is enhanced by rains that wash nutrients deposited on leaves (Dollinger and Jose 2018). According to Marsden et al. (2019), the abundance of soil fauna in AFS is greater than that in cropland and similar to or less than in forests. Furthermore, Sofo et al. (2020) stated that soil macrofauna are the key to increasing soil fertility, with four important groups having important roles in the bio-cycle of soil nutrients. There are four types of geophiles macrofauna: temporary active geophilous, temporary inactive geophilous, periodic geophilous, and geobionts.

4 Conclusion

Agroforestry could be both more productive and conservative if it is managed on the basis of natural ecosystems through an integrated organic cycle system. AFS can support sustainable food security and sovereignty programs in Indonesia because it can simultaneously generate meal, wood, fibre, manure, energy, water, oxygen, medicine, spirituality, and nature tourism. Natural ecosystem oriented management of land and biological resources can provide economic, environmental, social, and cultural benefits. Therefore, it has the potential to improve the environment and people's lives more dignified and sustainable.

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Intensification of Agroforestry Systems in Community Forests to Increase Land Productivity and Sustainable Food Sovereignty

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1 Introduction

The need to roughly double food production in the next few decades, particularly as demand from the developed world increases rapidly, is a fundamental challenge for global food security (Godfray et al. 2010). Pretty and Bharucha (2014) argues that chemical inputs, genetic engineering, and mechanization are frequently utilized to increase yields. However, the leading causes of a wide range of social and environmental issues are conventional agriculture, climate change, biodiversity destruction and ecosystem disintegration, land depletion, water shortages, and social structure

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disturbance (Godfray et al. 2010; Pretty and Bharucha 2014). It is necessary to move away from a narrow focus on yields and towards more multifunctional agriculture, which in the context of sustainable intensification, also complies with (and ideally enhances) broader societal and environmental goals (Pretty and Bharucha 2014; Waldron et al. 2017). Agroforestry is one of the most multifunctional forms of agriculture in physical and human geography (Waldron et al. 2017). Agroforestry can increase yields depending on crop type and local conditions, and the level of expertise is frequently studied for environmental benefits and peasant to assist farmers' organizations (Pretty and Bharucha 2014).

Tropical ecosystems have a higher net primary productivity because they are more likely to be supported by a fast organic cycle than the low fertility of old acidic soils. The high plant growth and organic cycle are supported by high temperature, rainfall, humidity, and light intensity throughout the year (Agus 2018). Therefore, agroforestry development with an integrated bio-cycle system (IBS) has increased benefits in the environmental, economic, socio-cultural, and health sectors (Agus 2018). This system is multifunctional and multiproduct, which can meet the basic needs of daily, monthly, annual, and decadal income in the short, medium, and long term for small, medium, and prominent stakeholders. IBS can simultaneously produce food, feed, shelter, fertilizer, energy, medicine, water, oxygen, and ecotourism to support sustainable food sovereignty programs and sustainable development (Agus 2018).

The increase in yield corresponds to the ecosystem services of some trees, including improved soil nutrient status (i.e., through fixation of nitrogen), decreased crop stress (i.e., extreme temperatures and precipitation), lower soil erosion (binding soil to roots), and water supply control (hydraulic uptake of deep water by tree roots) (Waldron et al. 2015; Garrity et al. 2010). An additional critical element is resilience to climate change and its impacts, which can trigger significant hunger crises (sudden, widespread changes in weather, harvesting, price, and cost of input) (Garrity et al. 2010). Agroforestry improves plant resistance to the possible consequences of climate change, including drought and higher temperatures, as it increases water infiltration and accumulation, and reduces evaporation and extreme temperatures (Garrity et al. 2010; Charles et al. 2013).

As part of rural culture, a small community forest based on an agroforestry model has grown and become a significant source of income for many rural populations (Hernawan et al. 2020). There are three agroforestry systems in Java that local communities use: (1) the home garden (fenced-in gardens) surrounding buildings, with fruit and other trees, plants, and annual crops; (2) the tree garden (mixed trees) in the community areas of dense house clusters; and (3) fruit clusters of other trees planted in the past on the ground that was used for this purpose (Weersum 1982). In general, agroforestry practices in community forests (moor, yards, and other drylands) are an integral part of rural communities in Indonesia. Communities, especially in rural areas, continue to cultivate community agroforests due to the value of the commodities planted (food, energy, trade-in timber, and medicinal plants) by optimizing land use (Zhang et al. 2019). The exploitation of agroforestry provides direct benefits to managers and the environment, in addition to the ecosystem (von Maydell 1986; FAO 2005; Riedel et al. 2019). Although it is realized that the crop productivity in community forests with agroforestry patterns is still not optimal, a focus on crop productivity has a positive impact on increasing food production. Obstacles faced by community forest farmers include non-intensive, part-time, and non-market-oriented cultivation; poorly understood cultivation technology; and lack of assistance (Ashari et al. 2016). Given the significant role of agroforestry, further studies are needed to provide direction for an optimal agroforestry silvicultural system, especially in the case of Indonesia, where the food security challenges faced will be even more severe due to land-use changes and climate change. To increase food production and adapt to climate change, many studies and applications of agroforestry have been carried out on community forest lands. Intensification of agroforestry on community forest land is thought to contribute to increasing community forest food production. To synthesize and formulate the results of research on the application of agroforestry intensification for increasing food production, a systematic review of published articles related to silviculture of food-producing agroforestry in Indonesia has been provided.

According to Belsky (1993), competition between annual and perennial crops remains a severe obstacle to the use of agroforestry in community forests (small scale) for food crop production. However, there is no unified theory regarding the ideal competition management formulation for agroforestry systems (Wu et al. 2020). This chapter aims to synthesize a formula for increasing the productivity of food crops in agroforestry community forests in Indonesia to contribute to food security and sovereignty.

2 Methods

Studies have been carried out on agroforestry, community food forests, innovation, and agroforestry applications that potential communities have applied to achieve food security. In addition, data and information on the effect of intensification on food crop production/agriculture in agroforestry systems were obtained from the following sources: (1) results of research conducted by the Research and Development Institute for Agroforestry Technology about increasing land productivity through agroforestry, on community forest lands; (2) studies on several food crop productions in agroforestry patterns; and (3) reference studies on the current status of agroforestry development and policy recommendations for applying silvicultural agroforestry for national food security.

Based on the aforementioned data, information, and observations of current agroforestry developments, a concept of agroforestry intensification and policy recommendations for the application of agroforestry intensification for national food security can be formulated. This chapter used a literature review method, following the procedures of for the determination of the following criteria: (1) criteria for usability of data obtained from published scientific manuscripts or reports on research results, nationally and globally (proceedings and journals); (2) criteria for relevance of food ingredients from community forests, namely, types of tubers, tubers, and plant parts (stems) with high carbohydrate content; (3) whether the type of food crop selected is adaptive (shade-resistant) for agroforestry; (4) types of traditional food crops used by the people of Indonesia; and (5) types of plants that have high potential to be processed as a source of carbohydrates, based on research results. The collected reference data were qualitatively analyzed and synthesized.

The criteria for acceptable literature and other specific criteria included (1) geographic location in Indonesia, (2) research results, (3) location in community forests, (4) intensification of agroforestry for food security, and (5) indicators of treatment results. This study focuses on primary data from agroforestry intensification in community forests, in the context of food productivity (agroforestry silvicultural treatment of food production).

3 Results and Discussions

3.1 Environmental Engineering for Increasing Crop Productivity

Traditional agroforestry is carried out on relatively narrow land; the application is minimal, and subsistence and maintenance are not intensive (Suryanto et al. 2017; Sardjono et al. 2003; Roshetko and Manurung 2009). The characteristics of subsistence scale management are observed on a narrow land with various plant types, random cropping arrangements, and non-intensive maintenance (Sardjono et al. 2003). The contribution of agriculture-silviculture is under the synergistic pattern of timber versus non-timber forest products, showing a harmonious balance between diversity and income (Duffy et al. 2021).

Agroforestry moderation certainly requires more intensive action on a scientific basis, so that multiple (economic, social, and environmental) functions associated with sustainable community forests and prosperous communities can be achieved, which is the goal of forest management in Indonesia. However, in some developed countries, strategies to naturally increase conventional agriculture yield (poor environmental performance) dominate the debate on food production, hindering the adoption of more multifunctional alternatives such as agroforestry (Waldron et al. 2017). The silviculture approach primarily implemented in Indonesian forest plantations is known as "intensive silviculture," which includes the selection of superior seeds, environmental manipulation, and pest control (Soekotjo 2004). In the long term, obtaining sustainable productivity of a crop will depend on land preparation, control of wild vegetation, proper planting methods, fertilizers, and plant genetic material. With respect to this, the following elements of intensive silviculture require attention to ensure sustainable production: (1) selection of species, provenances, and families; (2) high quality seedlings; (3) land preparation and weed control; (4) use of fertilizers; (5) spacing; (6) proper management; (7) available funds.

Intensive silviculture that has not been widely implemented in the community provides an opportunity to approach a combination of agroforestry methods that the community has long applied. Agroforestry silviculture combines intensification of community-forest silviculture (concept and implementation have gaps) with agroforestry patterns (traditional to the modern gap) to achieve sustainable forest and land management. The existence of multiple products/crops producing food from community forests leads to intense management by farmers (Roshetko and Manurung 2009). In some developed countries, conventional agricultural applications still dominate (Lynam et al. 2016), and there is often a concern that the continuous intensification approach will reduce the presence of trees in the agroforestry system (Siebert 2002; Waldron et al. 2015). However, the concept of intensifying agroforestry in community forests to increase food productivity in Indonesia does imply conventional intensification that removes environmental functions from forests and land, tending more towards alternative multifunctional agroforestry (Waldron et al. 2017).

The intensification of agroforestry management in community forests seeks to divide the space for seasonal crops as optimally as possible, in addition to tree stand rotation. The dynamics of spatial division in agroforestry systems in Indonesian community forests can be classified into three categories: early agroforestry (annual crop area >50%), intermediate agroforestry (annual crop area 25–50%), and advanced agroforestry (annual crop area <25%) (Suryanto et al. 2012). As food crops demand more space under the trees, food production agroforestry is developed by maintaining the dynamics of spatial division in early agroforestry or mid agroforestry categories (Suryanto et al. 2012). However, in general, current agroforestry practices in community forests are conducted either without thinning or with only 40% thinning, primarily using seedlings from natural saplings (72%), as well as low usage of superior seeds (12%) (Roshetko and Manurung 2009).

In the agroforestry pattern, the interaction pattern between seasonal and perennial crops affects the growth and production of cultivated crops. This interaction is influenced by soil fertility (Moreno 2008), local climate (Moreno et al. 2007), and functional tree group (Rivest et al. 2013).

The interaction between tree crops in agroforestry systems is competition for light, nutrients, and water (Mantino et al. 2021; Rizwan et al. 2020). The amount of light received affects the crop species (Charbonnier et al. 2017; Miah et al. 2018; Rizwan et al. 2020). Dupraz et al. (2018) stated that light affects the crop species the most in an alley cropping agroforestry system, compared to other factors. The lower the light received by plants, the lower is the root growth (Caron et al. 2018). Therefore, light-water-nutrient competition is interrelated, and roots play a critical role, making it easier to determine the level of competition between plants by examining the nutrient status in roots (Wu et al. 2020). Therefore, a resource sharing technique is needed to maximize positive interactions and minimize negative interactions between crops and trees, which include choosing a combination of species, optimal spacing, land preparation techniques, planting techniques, maintenance (thinning, pruning, singling, advanced fertilization, and pest and disease control), and harvesting techniques.

3.2 Integrated Crop Management

Mixing plant types in an agroforestry pattern is considered the proper agroforestry silviculture technique to optimally produce all constituent plants. Different types of trees grown with crops require different growing spaces, nutrients, water, and light; thus, the spacing needs to be adjusted. Early agroforestry (i.e., annual crop area >50%) can use intolerant food crops (maize, peanuts, cassava, and upland rice). In intermediate or advanced agroforestry, the dominant intolerant annual crops must be combined with shade-tolerant and semi-tolerant crops (e.g., coffee, tubers, shade-resistant soy/peanut varieties, coffee, cardamom, and ginger), as presented in Table 1. Food crops cultivated under tree stands with a light intensity of 30%–70% are tubers (Rosmiah et al. 2014; Direktorat Budidaya Aneka Kacang dan Umbi/DBAKU 2013).

At mid- and advanced-level agroforestry with a multilayer production approach via intensive species enrichment, tree options are multipurpose tree species (MPTS) that produce food supplements and income (Suryanto 2014; Waldron et al. 2017; Belsky 1993). The selection of food-producing trees such as fruits (durian, mangaThe selection of food-producing trees such as fruit trees (durian, mango, and mangosteen) is also an alternative to producing food that can be harvested seasonally by the community. Fruit agroforestry (cashew, durian, and cocoa) requires more intensive maintenance than timber plantations because it is related to fruit food productivity. Cultivation of trees outside of forests has grown to support production and ecosystem functions, mangosteen etc.) is also an alternative to producing food that can be harvested seasonally by the community. Fruit agroforestry (cashew, durian, and cocoa) demands more intensive maintenance than timber plantations because it is related to fruit food productivity. Cultivation of trees outside the forest (trees outside the forest) has grown to support production and ecosystem functions (FAO 2005).

3.3 Maintenance of Plantation

Maintenance of wood in the agro-plantation system aims to increase the production and quality of wood and maintain the tillage area for seasonal crops (Soekotjo 2004; Suryanto et al. 2017). The maintenance components in community forest development include the following: embroidery, weeding, fertilizing, bulking, pruning, singling, and thinning. In addition, pollarding, commercial thinning, and root pruning are needed to support agroforestry systems to remain active with seasonal crops throughout the community forest management cycle (Suryanto et al. 2017). However, yard agroforestry and complex agroforestry forms still implement experimental forms of intensive silvicultural applications, such as fertilization, spacing, and pruning (Bazié et al. 2012; Dilla et al. 2019, 2020).

Table 1 The combination of food crops under community forests

No	Combination of agroforestry plant types	Food crops productivity	Source
1	Intercropping of shade-resistant upland rice genetic varieties, shade-resistant soybean varieties, and shade-resistant corn varieties (combination of wood with 60% shade level of trees)	Rice 2.41–4.37 t/ha; soybean 1.35–1.69 tonnes/ha, shelled dry maize 3.9 t/ha	Abidin and Puwatu (2016)
2	Intercropping 3 Varieties of Ginger Ginger on Puncture Class II age/light intensity 50–58%, KU I/intensity 68–77%, and Poor increment/light intensity 87–92% (manure, SP36 fertilizer, and KCl)	in poor crop agroforestry increments with a light intensity of 87–92%) were able to increase the productivity of ginger	Gunawan and Rohandi (2018)
3	Gamal + Coffee; Dadap + Kopi and Cempaka + coffee in Lampung. Shade/no shade. Shade spacing 4 m × 4 m and coffee spacing 2 m × 2 m	Coffee production aged 5 years with shade (1364.4 s/d 1573.2 kg/ha), without shade 1290.5 kg/ha	Evizal et al. (2010)
4	Shade Leda (51%), Shade Suren 30% + coffee in South Bandung	Coffee production yield 3127.17 kg/ha and under suren 1173.74 kg/ha	Fathurrohmah (2014)
5	Intercropping of Taro (Colocasia esculenta L. Shott) in *Sengon*, Jabon, and manglid stands four years old, 3 m × 2 m spacing (light intensity 40–56%)	Type of production of taro tubers under Jabon stands (2333.0 g/plant), *sengon* stands (1597.0), manglid (607.6 g/plant and monoculture (739.4 g/plant)	Sudomo and Hani (2014)
6	Intercropping Soybean in mixed trees (light intensity 22%)	Soybean production 0.82 ton/ha. Forest land based on various trees is potential for the organic cultivation of soybeans	Mardhikasari et al. (2015)
7	Pine + Shade-resistant corn	Pioneer varieties can adapt well to low light environmental conditions under pine stands and produce higher yields of 1.96 tonnes/ha than kretek varieties, namely, 0.61 ton/ha	Kusuma (2004)

(continued)

Table 1 (continued)

No	Combination of agroforestry plant types	Food crops productivity	Source
8	*Michelia camphaca* + maize Tasikmalaya West Java Spacing for manglid wood 3 m × 3 m; The best 3 m × 2 m and 2 m × 2 m	Weight of dry shelled maize in agroforestry cropping patterns resulted from the interaction of hybrid varieties at a manglid spacing of 3 m × 3 m (8775 kg/ha). Production of dry maize for hybrid varieties (8563 kg/ha) is higher than for local varieties (6029 kg/ha)	Sudomo and Rohandi (2017)

3.4 Fertilization

A decrease in soil fertility occurs in many tropical wet areas. Many agricultural land management systems extract significant amounts of biomass continuously and do not return the remaining biomass to land. This condition can result in a decrease in crop production during the next cycle. Therefore, fertilization is performed to increase the availability of nutrients required by plants. In agroforestry, input intensification can be performed using organic fertilizers derived from plant residues, manure, compost, or other sources of organic matter (Hilmanto 2009).

Providing additional nutrients through fertilization is another form of land management, in addition to spacing arrangements for receiving an adequate amount of light. This treatment is essential, considering that soil fertility affects plant growth (Moreno 2008), and compensates for material loss during harvesting (Borden and Isaac 2019). With respect to reduction of the risk of leaching/nitrification from excess nutrient input, tree species contribute to the absorption of excess nutrients from annual crops (Harmand et al. 2007). In an ecosystem with high heterogeneity, such as agroforestry, a strategy is needed to provide the nutrient resources needed by each plant species to develop optimally, even though determining the appropriate form of technical fertilization application is challenging (Borden and Isaac 2019). Many recommendations for fertilization techniques on ideal agroforestry systems have been applied to certain agroforestry land conditions, such as soybeans (Rizwan et al. 2020), maize (Bertomeu et al. 2011), and coffee (Harmand et al. 2007).

Some general technical considerations in the design and management of agroforestry systems so that soil fertility is maintained and that fertilizer input can be minimized are as follows (FORDA 1997): (1) Use of trees or shrubs (as well as seasonal plants) Nitrogen binding (*Gliricidia sepium, Leucaena leucocephala*), *Paraserianthes falcataria, Erythrina spp, Albizzia spp, Calliandra calothyrsus*); (2) Planting trees and shrubs (and also seasonal crops) along the contour line as a barrier to control soil erosion (3) Align the time pruning with the nutrients needed by plants annuals (4) Perform crop rotation for annual crops. Seasonal, nitrogen-fixing legume crops are best planted after other types of planting to restore the reduced nutrient availability caused by the harvest. (5) Plant ground cover crops or plants that produce green manure in lands that are in a fallow period (*Desmanthus virgatus, Clitoria ternatea, Centrocema pubescen, Vigna radiata, Vigna sinensis, Sesbania rostrata*). In addition, research results of the intensification of fertilization contribute to increasing food production in agroforestry community forest lands presented in Table 2.

3.5 Pruning

Light regulation measures in agroforestry systems can be done by removing dead, diseased branches and improving wood quality, manipulating the size and shape of the canopy to maintain biomass productivity, and maintaining competition with understorey and thinning selection to improve wood quality, singling as well as maintaining production such as fruit, leaves, branches (Huxley 1999). Initial spacing is one of the most fundamental and vital factors in forest management that affects the final yield (Cardoso et al. 2013). Therefore, pruning is needed, and tree maintenance can also increase the intensity of light that enters the canopy.

Suryanto et al. (2017) found that silvicultural measures to remain in early agroforestry (seasonal crop cultivation > 50%) are pollarding (shoot pruning) and root pruning. This action is to open the vertical and horizontal space together so that the area of the crown closure will be reduced. Pruning the trees will have a positive effect on tree crops and agricultural/seasonal crops. Research by Na'iem and Sabarnurdin (2003) shows that pruning branches and even stems to stay 6 m above the ground is very beneficial because it can increase the light intensity, which is very beneficial for other plants with lower canopy and will also produce 6 m of final round wood. Suryanto et al. (2009) state that fallow management is prioritized on reducing crown density through silvicultural techniques (pruning canopy and thinning) to increase light availability so that it can support more optimal seasonal cultivation. Agroforestry is dominated by trees so that the effective cultivation area for crops is reduced, which results in a fallow period. The fallow period is the time when the land is rested from planting seasonal crops. Some of the research results on the effect of plant maintenance by pruning trees are presented in Table 3.

3.6 Thinning

Thinning treatments in agroforestry systems are positive for seasonal crops kitt (Nicodemo et al. 2016). Furthermore, thinning and regulating the spatial distribution of plants can be used for land optimization in agroforestry (Zhang et al. 2019; Livesley et al. 2000; Kittur et al. 2016). Especially for spatial distribution, apart from providing more space for light entry, it can also reduce water and nutrient competition because it can reduce root length density, root diameter, and root surface area

Table 2 Fertilization intensification on the productivity of agroforestry plants

	Location	Treatment input	Findings	Source
1	*Sengon* and maize (Barugae Village, Mallawa District, Maros Regency)	Soil processing, liming, NPK fertilizer and manure	Fertilization can increase *sengon* growth and dry-shelled corn production	Miliang (1991)
2	Trees + Banana (Putukrejo, Kalipare and Kedungsalam, Donomulyo, Malang District)	Intensification of calcareous	land management Intensification of land management increases banana production and varieties	Febrianty (2003)
3	*sengon* + cucumber (Cucumis sp) + peanuts (Kab Banjar)	With intensive maintenance (fertilizing, cleaning weeds, eradicating pests and diseases and soil mounding)	Increasing cucumber yields to 16 tonnes / ha and peanuts 1 ton / ha	Hani and Mile (2006)
4	Trees + coffee (Gunung Walat, Sukabumi)	Dose of 25 g and 50 g decastar per tree Fertilization at a dose (urea 250 g + TSP 100 g + KCL 180 g) / ha	Increased coffee bean yield by 297% and 730% and coffee shoots increased after pruning	Budi et al. (2009a), Budi et al. (2009b)
5	Trees + tubers (Gunung Walat, Sukabumi)	Urea dose 7.5 g + SP 36 2.5 g + KCL 5 g, urea dose 15 g + SP 36 5 g + KCL 10 g, and urea dose 22.5 g + SP 36 7.5 g + KCL 15 g	All three increase tuber weight up to 115.3%, 186.95%, and 236.31%, and application of mycorrhiza can increase plant production by 19%	Budi (2009)
6	Jelutung + chilies + leeks + mustard greens + corn + ferns (Sumba Island)	Amelioration with manure and ash	Increase annual crop productivity and the growth of jelutong plants until the age of 3 years	Widyati et al. (2010)
7	Intercropping of cassava varieties Inwood stands	Fertilizing with 300 kg of urea, 200 kg of SP36, 200 kg of KCl, 500 kg of dolomite, 5 tons/ha of manure, and weeding with herbicides	Feasible to develop with tuber yields reaching 60 t / ha and B / C ratio 1.33–3.17	Radjit et al. (2014)
8	Corn-coconut and Soybean-coconut (Maluku Island)	Organic Fertilizer + NPK + Urea	Soybean(1,134 kg / harvest + LER = 1.76) and corn (6,019 kg / harvest + LER = 2.15)	Hidayat et al. (2020)

(continued)

Table 2 (continued)

	Location	Treatment input	Findings	Source
9	Trees + arrowroot	Ammonium sulfate 350–650 kg or urea 156–290 kg / ha / season; TSP 300 kg or SP36 as much as 375 kg / ha / season, and KCl 300 kg / ha / season	Shade < 30% yield 3–9.5 tonnes / ha; Shade > 30% 4.8–9.2 tonnes / ha)	Djaafar and Pustika (2010)

density (Zhang et al. 2019). Thus, in the end, the competition for roots will decrease (Schenk 2006).

Soekotjo (2004) reported the effect on woody plants as a result of thinning is (1) spurring diameter growth in individual standing stands, (2) decreasing of total area of the base stand per unit area, (3) produce a larger average diameter of standing stands, (4) inhibit or reduce the spread of pests and diseases, and (5) reduce natural tree mortality. On the other hand, if the growing space is extensive, it will spur the growth of large branching; knots will also be significant, affecting the quality of the wood, so we need pruning work. Commercial thinning is carried out by cutting down economically valuable trees to reduce tree density and maintain community forests in early agroforestry (tillage >50%) (Suryanto et al. 2017).

In advanced agroforestry, it is not easy to implement throughout the cycle because canopy closure has occurred. In traditional community forests, intercropping will be stopped after the timber plant has grown to cover the food crops for about 2–3 years. In *sengon* plants, more than three years with a spacing of 3 m × 3 m. annual crops can no longer be planted (Mindawati et al. 2006). Therefore, thinning and pruning *sengon* are needed to continue to strive for *sengon* in early agroforestry. In addition, the results of thinning wood can be used for making containers or meeting firewood for the community.

4 Conclusions

The implementation of community forestry has been based primarily on knowledge passed on from generation to generation and market/subsistence use/demand for the results of cultivated plant commodities. Seasonal food crops, which are generally understorey, and perennial fruit trees, which are timber plants that have been developed for a long time, have contributed to the local food supply. Environmental engineering or land management can be carried out (1) via the use of tolerant varieties, (2) by thinning/pruning/tree spacing to make room for incoming light, (3) using fertilization, and (4) by optimizing the benefits of the existence of trees in the system. The empowerment of the community to achieve food security could be achieved by (1)

Table 3 Some research results on the effect of tree pruning on agroforestry crops

	Location	Treatment	Findings	Source
1	Manglid 2 years + peanut Ciamis, West Java	Pruning intensity of manglid wood 75% and 50%	Manglid wood pruning intensity increased peanut production and agroforestry LER value of 1.78	Sudomo (2013)
2	Experimental Garden, Bunga Mayang, North Lampung	Calliandra + corn	pruning which intensively *Caliandra* will provide benefits for corn plants or hedgerows, need to be widened	Hairiah and van Noordwjik (1993)
3	Darungan Village, Sutojayan District, Blitar, East Java	Pruning Teak + cassava	The effect of the tree on the availability of light in the intercrop can be reduced by pruning the teak trees	Trimanto (2003)
4	Forest Pine, Klampok Village, Singosari District, Malang Regency,East Java	Pinus + corn	Pruning pine trees increases light penetration thereby increasing chlorophyll content followed by an increase in photosynthesis rate	Maharani (2004)
5	Klampok Village, Singosari District, Malang	Corn + pine	Pruning and nitrogen treatment 150 kg/ha gave the highest maize production compared to other treatments	Efendi (2004)
6	Klampok Village, Singosari District, Malang, East Java	Soybean + pine	Pruning 1/3 of the canopy of light intenistas pine trees (from 20 to 23%) at the beginning (0 dd) and at maximum vegetative time (40 dd) by 23% to 28%	Kurniawan (2004)
7	Klampok Village, Singosari District, Malang, East Java	Corn + pine	Corn plants planted under pruned pine stands give higher yields of 1.61 tonnes/ha than those that are not pruned, namely 0.96 t /Ha	Kusuma (2004)

(continued)

Table 3 (continued)

	Location	Treatment	Findings	Source
8	Nglanggeran Village, Patuk District, Gunung Kidul Regency, DIY Province	Trees + Seasonal Plants	Fallow management is prioritized on reducing crown density through canopy pruning and thinning techniques to increase the availability of light to support more optimal seasonal crop cultivation	Suryanto et al. (2009)
9	Tenggerraharja Village, Ciamis, West Java	Manglid 2 years old + Corn	Pruning manglid up to 75% increases the field of seasonal crops and maize productivity	Sudomo (2012)

creating new shade-resistant varieties, (2) developing communal commercial agroforestry management, (3) applying intensive silvicultural concepts, and (4) utilizing production facilities and infrastructure (subsidized seeds and fertilizers).

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Sustainable Development of Agriculture: Modeling and Management to Ensure Food Security

Elena G. Popkova

1 Introduction

Food security and its insufficiently high level are the key problems of humanity. Despite the intensive progress of the economy, society, and technologies in the twenty-first century, this problem preserves its importance. It became especially topical amid the 2020–2021 crisis and the COVID-19 pandemic (de Paulo Farias and dos Santos Gomes 2020; Fan et al. 2020; Popkova et al. 2020b).

The problem of food security has two potential solutions, both of which envisage the establishment of a balance in the food products market—but in different ways. The first solution is the reduction of demand for food. The simplest, but difficult to achieve, method, in this case, is the reduction of the planet's population. However, even in this case, if the current technological mode is preserved, the food products market could still experience a deficit of food due to reduction of offer—e.g., under the influence of climate change and exhaustion of the soil.

A more complex method of the practical implementation of this solution is the reduction of humanity's need for food with the preservation of the current population. This could be achieved through a more careful attitude towards food (improvement of the conditions of storing, refusal from disposal of eatable products), but then the problem will be solved only partially and temporarily. There is a possibility of genetic mutations of humans (including artificial mutations), which will either reduce their need for food or will allow consuming non-organic food, which will transform the demand for food. However, the consequences of this way might be catastrophic and irreversible. Thus, on the whole, the first solution is improbable and very risky.

The second solution envisages sustainable development of agriculture—i.e., the simultaneous growth of efficiency in agriculture with the increase of the quality and

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safety of food and the reduction of food prices (due to an increase of the competition between sellers). This solution is aimed at the offer and is more reliable and perspective, which is proved by the inclusion of sustainable agriculture in the formulation of the sustainable development goal that is connected to the provision of food security (2 "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture": UN 2021).

The practical implementation of the second solution envisages the improvement of the organizational schemes and technologies of agriculture. A barrier on the path of solving the problem of ensuring food security through the improvement of the offer in the food market is the underdevelopment of the scientific and methodological basis for managing agriculture's sustainable development. In particular, the tools of management are not specified, and the specifics of their use in countries with different levels of food security are not determined, which is a gap in scientific knowledge.

To fill this gap, we determine the contribution of various tools to the provision of sustainability of agriculture's development:

– digitalization as a tool of improving the production technologies, which allows raising the automatization level and thus increasing efficiency, as well as reducing the dependence of agriculture on the natural and climate factors;
– innovations as a tool of improving the organization of agricultural entrepreneurship for optimization of its business processes;
– social entrepreneurship as a tool of raising corporate social and ecological responsibility of social entrepreneurship and its orientation at the implementation of sustainable development goals (primarily SDG 2);
– globalization and opening of the economy as a tool of the market stimulation of growth of effectiveness and competitiveness of agricultural entrepreneurship.

The following hypothesis is offered: the available tools contribute differently to the provision of agriculture's sustainable development in countries with different levels of food security. The goal of this paper consists in the modeling of agriculture's sustainable development with the complex use of various tools and development of recommendations for managing these processes in the interests of ensuring food security in countries with different levels of food security and in view of their specifics.

2 Literature Review

The theoretical basis of this research consists of the modern authors' works on the issue of agriculture's sustainable development: Popkova et al. (2021), Popkova and Sergi (2021), Popkova and Sergi (2020a), Popkova and Sergi (2020b), Popkova et al. (2020a), Sergi et al. (2019), Sazanova and Ryazanova (2019), Karanina (2020), Litvinova (2020), and Sofiina (2020). The following works on the topic of food security, which provide and discuss various tools of its provision, are used:

Asitik and Abu (2020), Bannor et al. (2021), Kissoly et al. (2020), Vatanparast et al. (2020), and Zolin et al. (2021).

The performed literature review has shown a high level of elaboration of the issue of ensuring food security through sustainable development of agriculture at the level of fundamental science. The gap analysis has shown that at the level of applied science, there's a deficit of empirical studies, which leads to such gaps as fragmentary knowledge on the efficiency of using various management tools regarding the sustainability of agriculture and the non-systemic character of the experience of countries with different levels of food security.

This paper aims to fill the above gaps through the systemic modeling and generalization of the experience of countries with different levels of food security, as well as the development of applied recommendations for managing agriculture's sustainability with the help of various tools in these countries because of their specifics.

3 Materials and Method

The offered hypothesis is checked with the use of the methodology of economic statistics (econometrics). The samples containing four countries with different levels of food security each are created (Fig. 1).

As shown in Fig. 1, in countries with the highest level of food security (top 4), the average value of the corresponding index equals 82.10 points; in countries with

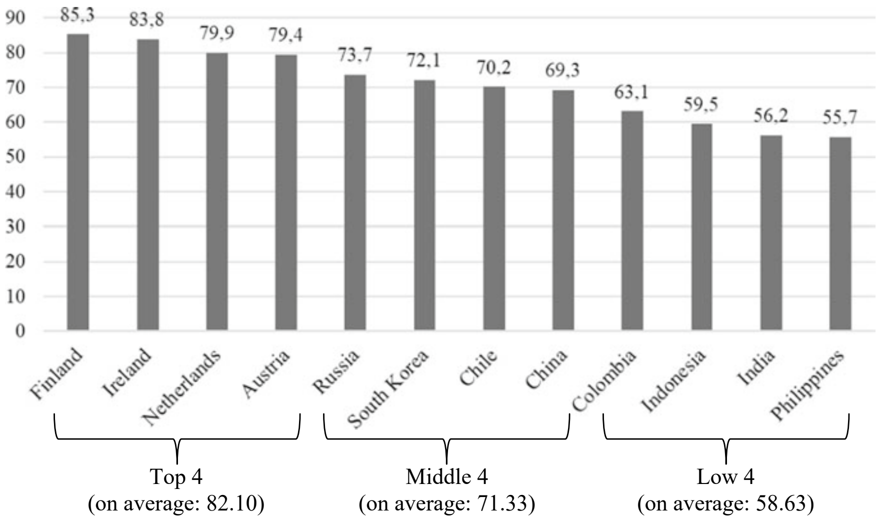

Fig. 1 The food security index in the countries of the sample in 2020, points 1–100. *Source* Compiled by the authors based on The Economist Intelligence Unit Limited (2021)

the average level of food security (middle 4)—71.33 points (by 13.12% lower as compared to top 4); and in countries with the low level of food security (low 4)—58.63 points (by 17.81% lower as compared to middle 4). Regression analysis is used to determine the regression dependence of the results of ensuring food security (affordability index (AF), availability index (AV), and quality and safety index (QS)) on the factor of natural resources and resilience index (Agr_{sust}). The statistical data on these indicators for the sample of countries in 2020 are given in Table 1.

Also, the regression dependence of natural resources and resilience index (Agr_{sust}) on the application of various tools are determined: digitalization (dg), innovations (ia), social entrepreneurship (se), and globalization (go). The statistical data on the above indicators for the sample of countries in 2020 are given in Table 2.

The following model (a system of equations of multiple linear regression) is created:

$$\begin{cases} AF = a_1 + b_1 * Agr_{sust}; \\ AV = a_2 + b_2 * Agr_{sust}; \\ QS = a_3 + b_3 * Agr_{sust}; \\ Agr_{sust} = a_4 + b_4 * dg + b_5 * ia + b_6 * se + b_7 * go. \end{cases}$$

Table 1 The results of provision of food security and sustainability of agriculture in the sample of countries in 2020

Country		Results of provision of food security			Factor
		Affordability index	Availability index	Quality and safety index	Natural resources and resilience index
		AF	AV	QS	Agr_{sust}
Top 4[a]	Finland	90.6	82.0	93.8	73.2
	Ireland	92.2	75.7	94.0	73.2
	Netherlands	90.7	74.5	88.7	61.5
	Austria	89.5	70.8	94.3	61.8
Middle 4[a]	Russia	87.2	64.7	84.1	55.0
	South Korea	81.8	67.7	78.4	56.1
	Chile	77.0	66.1	80.5	54.7
	China	72.8	73.7	72.5	51.2
Low 4[a]	Colombia	65.8	58.5	74.1	55.4
	Indonesia	73.5	64.7	49.6	34.1
	India	55.0	64.3	59.0	40.8
	Philippines	66.5	57.6	52.0	35.8

[a]Countries' position in the ranking of food security by the value of the global food security index in 2020 (The Economist Intelligence Unit Limited 2021)

Source Compiled by the authors based on The Economist Intelligence Unit Limited (2021)

Table 2 The tools of agriculture's sustainability management in the sample of countries in 2020

Country		Digitalization level (digital competitiveness), points 1–100	Innovative activity of business (global innovation index), points 1–100	Social entrepreneurship index, points 1–100	Level of economy's globalization and openness (globalization index), points 1–100
		dg	ia	se	go
Top-4[a]	Finland	91.130	57.02	53.698	87.70
	Ireland	79.232	53.05	57.565	85.54
	Netherlands	92.567	58.76	67.478	90.68
	Austria	83.127	50.13	51.643	88.56
Middle-4[a]	Russia	59.950	35.63	61.147	71.94
	South Korea	92.252	56.11	59.327	78.48
	Chile	61.518	33.86	42.830	76.08
	China	84.105	53.28	46.685	64.28
Low-4[a]	Colombia	46.450	30.84	37.395	63.66
	Indonesia	50.075	26.49	45.161	63.22
	India	54.836	35.59	54.086	62.23
	Philippines	50.031	35.19	46.773	66.91

[a]Countries' position in the ranking of food security by the value of the global food security index in 2020 (The Economist Intelligence Unit Limited 2021)
Source Compiled by the authors based on IMD (2021), Institute of Scisentific Communications (2021), KOF (2021), WIPO (2021)

Correlation analysis is used to calculate the natural resources and resilience index with the use of various tools for the full sample of counties and groups of countries (top 4, middle 4, and low 4). The hypothesis is deemed proved if the signs of the correlation coefficients for the same tools are different for groups of countries and the full sample of countries. Based on the correlation coefficients, the most efficient (positive and high correlation) tools for each group of countries are selected.

4 Results and Discussion

To determine the contribution of various management tools to the provision of the natural resources and resilience index (in the full sample of countries), the following regression equation is built based on the data from Tables 1 and 2:

$$Agr_{sust} = -4.39 - 0.30 * dg + 0.78 * ia - 0.35 * se + 0.86 * go \quad (1)$$

According to Eq. (1), an increase of innovative activity of business by 1 point leads to an increase of the natural resources and resilience index by 0.78 points. An increase of the level of the economy's globalization and openness by 1 point leads to an increase of the natural resources and resilience index by 0.896 points. The level of digitalization and social entrepreneurship have a negative influence on the sustainability of agriculture (regression coefficients constitute −0.30 and −0.35, accordingly).

Multiple correlation equals 84.69%, which is a sign of a close connection between the indicators and reliability of the regression equation. Significance F equals 0.0422. Estimate F (F_{est}) equal 4.439, and table F (F_{tab}) for 12 observations and 4 variables ($k_1 = n = 4$, $k_2 = n - m - 1 = 12 - 4 - 1 = 7$) at the significance level $\alpha = 0.05$ equals 4.12. As $F_{est} > F_{tab}$ (4.439 > 4.12), F-criterion is observed (F-test is passed), and the equation is significant at the significance level $\alpha = 0.05$.

To check the offered hypothesis and to determine the differences in the efficiency of using management tools in countries with different levels of food security, a correlation analysis is performed based on the data from Tables 1 and 2 (Fig. 2).

The obtained results of the correlation analysis have confirmed the hypothesis and have shown that the full sample of countries is characterized by a positive influence (correlation > 0) of all four tools. The highest correlation is observed between the natural resources and resilience index and globalization (0.81); a high correlation is observed between the natural resources and resilience index and innovations (0.71) and digitalization (0.70); moderate correlation is observed between the natural resources and resilience index and social entrepreneurship (0.39).

The thorough research based on countries with different levels of food security has shown that in countries with the highest level of food security (top 4), the only tool of managing agriculture's sustainability is an innovative activity of business (correlation—0.07). In countries with a medium level of food security (middle 4),

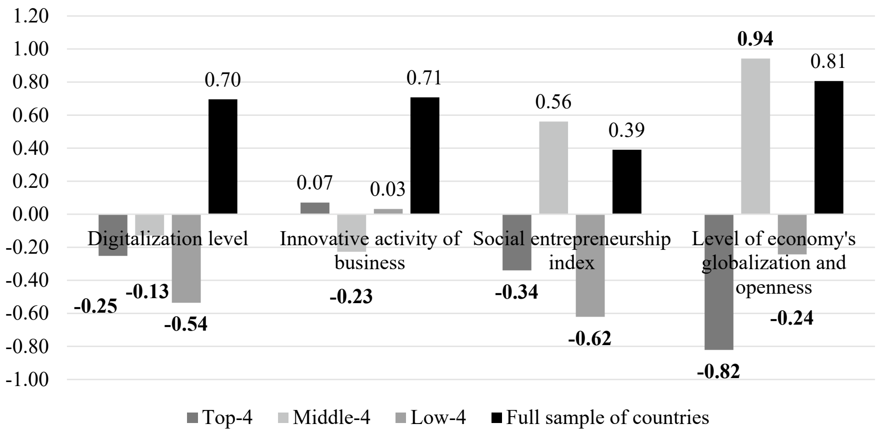

Fig. 2 Correlation between the natural resources and resilience index and the use of various management tools, fractions of 1. *Source* Calculated and compiled by the authors

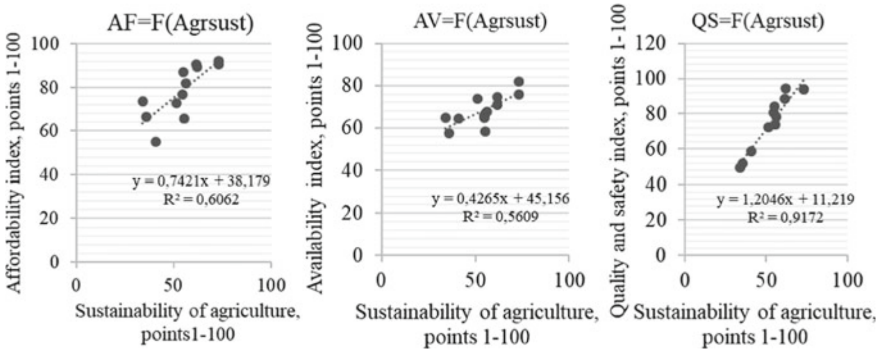

Fig. 3 The regression curves of the dependence of the results of ensuring food security on agriculture's sustainability. *Source* Calculated and compiled by the authors

the only effective tools for managing agriculture's sustainability are globalization and an increase of the level of the economy's openness (correlation—0.94).

In countries with a low level of food security (low 4), the only effective tool for managing agriculture's sustainability is an innovative activity of business (correlation—0.03). The regression curves in Fig. 3 reflect the dependence of results in the sphere of ensuring food security on the natural resources and resilience index (in the full sample of countries based on the data from Table 1).

As shown in Fig. 3, an increase of the natural resources and resilience index by 1 point leads to an increase of the affordability index by 0.7421 points (correlation—60.62%), an increase of the availability index by 0.4265 points (correlation—56.09%), and an increase of the quality and safety index by 1.20416 points (correlation—91.72%). Based on the obtained regression dependencies [Eq. (1) and regression curves in Fig. 3] and the selected tools (from Fig. 2) for countries with different levels of food security, the perspectives are determined and recommendations are offered for managing the sustainable development of agriculture in the interests of ensuring food security (Figs. 4, 5 and 6).

As shown in Fig. 4, to improve the management of agriculture's sustainable development in the top 4 countries, it is recommended to raise the innovative activity of entrepreneurship from 54.74 points to 96.79 points, i.e., by 76.82%. Due to this, the natural resources and resilience index will grow from 67.43 points to 100 points, i.e., by 48.32%. The advantages for food security will be as follows:

– increase of the affordability index from 90.75 points to 100 points, i.e., by 23.85%;
– increase of the availability index from 75.75 points to 87.81 points, i.e., by 15.92%;
– growth of the quality and safety index from 92.70 points to 100 points, i.e., by 42.05%.

As shown in Fig. 5, to improve the management of agriculture's sustainable development in middle 4 countries, it is recommended to raise the economy's globalization and openness from 72.70 points to 100 points—i.e., by 37.56%. Due to this,

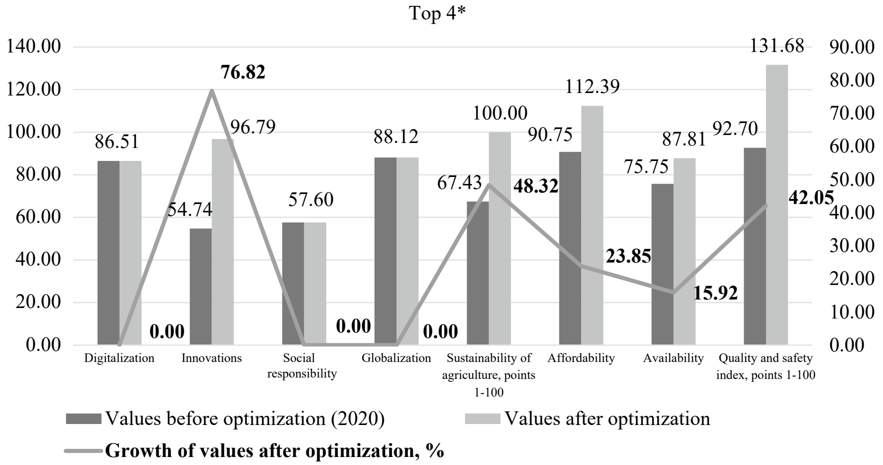

Fig. 4 The perspectives of ensuring food security in top 4 countries based on managing the agriculture's sustainable development. *Source* Calculated and compiled by the authors

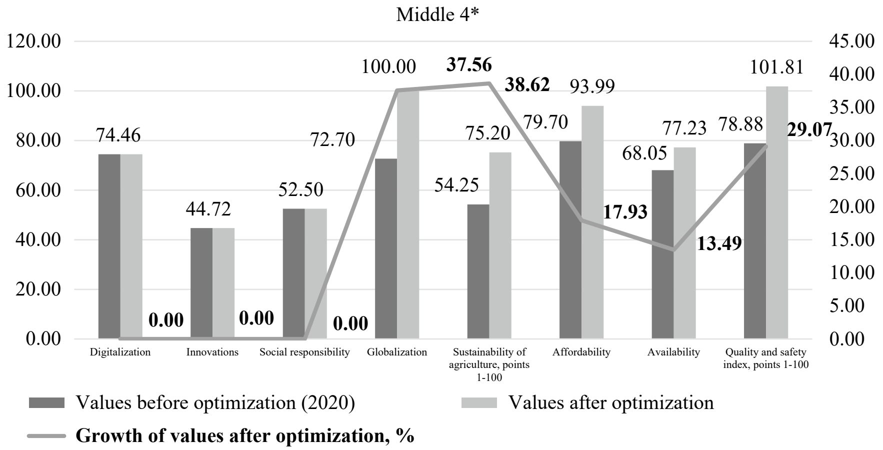

Fig. 5 The perspectives of ensuring food security in middle 4 countries based on managing the agriculture's sustainable development. *Source* Calculated and compiled by the authors

the natural resources and resilience index will grow from 54.25 points to 75.20 points—i.e., by 38.62%. The advantages for food security will include as follows:

– increase of the affordability index from 79.70 points to 93.99 points, i.e., by 17.93%;
– increase of the availability index from 68.05 points to 77.23 points, i.e., by 13.49%;
– growth of the quality and safety index from 78.88 points to 100 points, i.e., by 29.07%.

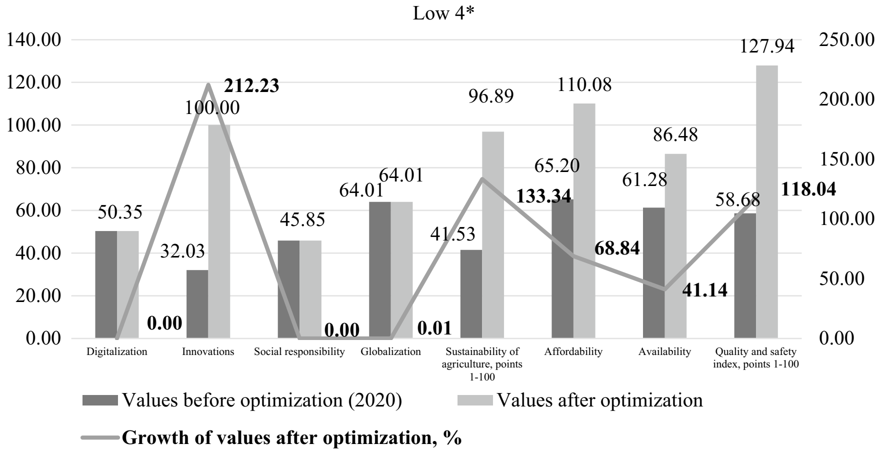

Fig. 6 The perspectives of ensuring food security in low 4 countries based on managing the agriculture's sustainable development. *Source* Calculated and compiled by the authors

As shown in Fig. 6, to improve the management of agriculture's sustainable development in low 4 countries, it is recommended to raise the innovative activity of entrepreneurship from 32.03 points to 100 points, i.e., by 212.23%. Due to this, the natural resources and resilience index will grow from 41.53 points to 96.89 points—i.e., by 133.34%. The advantages for food security will include as follows:

– increase of the affordability index from 65.20 points to 100 points, i.e., by 68.84%;
– increase of the availability index from 61.28 points to 86.48 points, i.e., by 41.14%;
– increase of the quality and safety index from 58.68 points to 100 points, i.e., by 118.04%.

5 Conclusion

Thus, the hypothesis has been proved. It has been shown that the available tools contribute differently to the provision of agriculture's sustainable development in countries with different levels of food security. The modeling of agriculture's sustainable development with the help of various tools has shown that the perspectives of the food security provision in countries with a high level of food security (shown by the example of the top 4) are connected to an increase of innovative activity of entrepreneurship by 76.82%.

In countries with a medium level of food security (shown by the example of middle 4 countries), it is recommended to increase the economy's globalization and openness by 37.56%. In countries with a low level of food security (shown by the example of low 4 countries), it is offered to increase the innovative activity of entrepreneurship by 212.23%. These recommendations will allow raising the sustainability of agriculture in the given categories of countries by 48.32%, 38.62%, and 133.34%, accordingly, and ensuring the improvement of all results for food security.

This paper's contribution to literature consists in the development of the scientific and methodological provision of managing agriculture's sustainable development through specifying the most effective tools and substantiating the necessity to take into account the specifics of countries with different levels of food security during the application of these tools.

Research limitations are associated with the fact that sustainable development of agriculture does not completely solve the problem of ensuring food security, in which, due to the author's recommendations, significant progress has been observed, but it is only partially solved (the maximum values of food security indicators are not achieved: 100 points).

So, in countries with a high level of food security, the quantitative availability of food does not exceed 87.81%, in countries with an average level of food security, the price availability of food does not exceed 93.99 points, and the quantitative availability of food does not exceed 77.23 points. In countries with a low level of food security, the quantitative food availability does not exceed 86.48 points.

This indicates that opportunities for solving food security problems through sustainable agricultural development are very broad but limited. Further studies should be devoted to the approbation of the offered recommendations, as well as the search for additional mechanisms for solving the problem of food security, which will complement and strengthen the recommendations for sustainable agricultural development and will completely solve this problem.

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Fostering Food Security

Drought Tolerant Maize in Africa: A Novel Technology Fostering Regional Food Security in Sub-Saharan Africa

Samuel Aderemi Igbatayo

1 Introduction

1.1 Preamble

Food security is a critical development goal, which has confronted Africa's policy makers and development partners in contemporary times. Persistent food and nutrition insecurity have spurred the international development community to enlist food security on the agenda of the Millennium Development Goals (MDGs), which spanned the period 2001–2015. It is note worthy that in 2015, sub-Saharan Africa recorded the worst indicators on the Global Hunger Index (GHI), with 33.5; the Horn of Africa (29.5), the Great Lakes region (27.7), Southern Africa (27.5) and West Arica (26) (Africa Union 2016). The inability of most African countries to meet the target of food security as part of the MDGs prompted policy makers across the continent to adopt a strategic balance in implementing the 2030 Sustainable Development Goals (SDGs) relating to food security (SDG2), through increased farm productivity and land management (SDG 15), while reducing the adverse consequences of the global climate change (SDG 18), and as fostering biodiversity (SDG14).

The Sustainable Development Goal2 aims to end hunger, achieve food security and improved nutrition, while promoting sustainable agriculture (United Nations 2015). However, indications are that the global community is hardly on target to achieve SDG2.1: zero hunger target by 2030. The food and Agriculture Organization of the United Nations (FAO), in its Global Food Security and Nutrition report for 2020, reveals that the combined projection of contemporary trends, driven by the size and demographic profile of population trends, total food availability, and the severity of inequality in food access, show a rise in the global prevalence of under nourishment (PoU), which is projected to exceed 840 million people by 2030. Table 1 reveals the

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Table 1 Number of undernourished (Million) across the world, 2005–2019 (Millions), with projections for 2030

	2005	2010	2015	2016	2017	2018	2019*	2030**
World	825.6	668.2	653.3	657.6	653.2	678.1	687.8	841.4
Africa	192.6	196.1	216.9	224.9	231.7	236.8	250.3	433.2
Asia	574.7	423.8	388.8	381.7	369.7	385.3	381.1	329.2

Notes *Projected values; **Projections up to 2030 do not reflect the potential impact of the COVID-19 pandemic; n.r. = not reported, as the prevalence is less than 2.5%
Source Adapted from FAO 2020

number of malnourished people across the world in 2019, together with projections for 2030.

1.2 Objectives

The major objective of this chapter is to explore food and nutrition security in Sub-Saharan Africa and dispersion of Drought Tolerant Maize in Africa to mitigate the scourge. The specific objectives are to;

i. assess the trends of food and nutrition security in Sub-Saharan Africa.
ii. determine the Prevalence of Undernourishment (PoU) in the sub-region.
iii. discuss the dispersion of DTMA across the sub-region.
iv. proffer recommendations aimed at mitigating food and nutrition insecurity in the sub-region.

1.3 Methodology

The study employs secondary data sourced from global, regional and national organizations, including the World Bank, International Institute of Tropical Agriculture, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Economic Commission for Africa, African Development Bank; as well as journals and other periodicals. This is complemented by interviews with stakeholders across the African region.

1.4 Organization of the Chapter

The chapter is subsumed into five sections. Section 1 presents the introduction, including objectives, methodology and organization of the chapter. Section 2 comprises the concept of food security, as well as global trends and developments.

Section 3 discusses the trend of food and nutrition security in Sub-Saharan Africa, while Sect. 4 highlights the role of maize in fostering food security and the emergence of DTMA across the sub-region. Section 5 ends the chapter with summary, conclusion and recommendations.

2 Food Security Concept and Global Trends

2.1 Food Security: A Conceptual Framework

Food security is a flexible concept; often meaning a lot of things to different people. Despite the recent evolution of food security as a concept, it had attracted more than 200 definitions in published writings (Maxwell and Smith 1992). The evolution of food security as a concept is traceable to the mid 1970s, in the light of international discourse on the world food crisis. Initially, the focus was primarily set on food supply challenges. This included the availability and, to some extent, the price stability of staple foods at the national, regional and global levels (FAO 2002).

The 1974 World Food Summit defines food security as 'availability at all times of adequate world food supplies of basic food stuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices (UN 1975).

In 1983, the Food and Agriculture Organization (FAO) of the United Nations expanded the concept of food security as follows:

> Ensuring that all people at all times have both physical and economic access to the basic food that they need (FAO 1983).

The World Bank (1986) also defines the concept of food security as:

> access of all people at all times to enough food for an active, healthy life.

The World Food Summit in 1996, defined food security at various levels, in a more elaborate conceptualization:

> Food security, at the individual, household, national, regional and global levels (is achieved) when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

The definition of food security was reinforced in the FAO's comprehensive report on global food security, titled: 'The State of Food Insecurity 2001':

> Food Security (is) a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 2002).

From the various definitions associated with food security, it is obvious that concept is hinged upon availability, accessibility, utilization and stability of food for all people at all times.

Adequate food availability at the national, regional and household levels sourced through market and other channels lies at the heart of food and nutrition security. At the household level, food security translates into both physical and economic access to foods deemed adequate, particularly the quantity, nutritional quality, safety and cultural acceptability to meet an individual's needs.

2.2 Global Food Security: Recent Trends and Developments

Challenges associated with food security can be particularly striking, especially in developing countries. This was brought to the attention of the international development community, with the unexpected spike in global food prices in 2007–78, following a sustained period of relatively stable global prices. The prices for food cereals assumed more than doubled proportions between early 2007 and mid-2008. In early 2008, the price of major agricultural inputs, including fertilizers, quadrupled and the price of fuel assumed doubled proportions. While food prices reduced after June 2008, they did not reduce to 2005 levels, but spiked again between June 2010 and June 2011 (World Bank 2013).

The food crisis associated with the recent global financial and economic crises was particularly severe in several countries in the developing world, with food riots breaking out in some of the most severely affected countries. The resulting incidence of hunger triggered poverty, which rose sharply between 100 and 200 million people around the world. Additionally, the crisis was acknowledged to have driven 63 million into malnourishment in 2008, a 6.8% rise over 2007 rates (Tiwari and Zaman 2010).

While the crisis associated with the recent food prices has largely subsided, the challenges of global food and nutrition security remain. The estimates of malnourished people around the world are revealed in the 2013 FAO report, titled, "The state of food insecurity in the world". Major features of the report reveal about 842 million people around the world, or 12% of the world population was unable to meet their dietary energy needs in 2011–13, a reduction from 868 million in its report for the 2010–12 periods. Therefore, about one in eight people around the world was probably humbled by chronic hunger in the period under review. The report shows that the majority of the world's malnourished people—827 million of them—are found in developing countries, where the proportion of the undernourished is now estimated at 14.3% in 2011–13. While the proportion of undernourished segment of the global population continues to decline, the degree of progress is deemed inadequate meeting international targets established to measure the progress against global hunger.

The international community had engaged in concerted efforts to mediate global food insecurity. An example is the 1996 World Food Summit (WFS) target, which seeks to reduce by half the number of hungry people; another is the 2000 Millennium Development Goal (MDG) hunger target, which is to reduce by half the level of malnourished people around the world by 2015. It is worthy to note that both targets have 1990 as the beginning year and 2015 as the target year. It is therefore clear in the FAO (2013) report that the deviation from actual target is increasing more rapidly for the WFS target than that of the MDG, particularly in the developing world. In order to achieve the WFS target, the number of malnourished people in the developing countries would need to be pruned to 498 million by 2015, a target that is largely unattainable worldwide. However, it should be noted that several individual countries are on the path to meet the WFS target, with 18 countries already meeting the target in 2012. On the other hand, the MDG hunger target is less problematic than the WFS target, and the divergence from its trajectory appears relatively small. The assessment estimated malnutrition in the developing world at about 24% of the population in 1990–92, translating into an MDG target of 12%. The PoU in developing regions would be slightly above the MDG target should the average annual reduction over the previous 21 years continue to 2915 (FAO 2013).

3 The State of Food Security in Sub-Saharan Africa (SSA)

3.1 Food Security in SSA: Emerging Trends and Challenges

The global financial and economic crises, which emerged in 2007–08, have exacerbated food and nutrition security challenges in sub-Saharan Africa. While the trend has been reduced marginally, the long-term prospects in the region's undernourishment profile are not in doubt. For example, in the past couple of decades, the additional number of people living in hunger in the region more than doubled, from 14.9 million people in the 1990–92 to 1995–1997 periods to 24.8 million for the 2004–2006 to 2009 periods. In East Africa, the sub-region with the largest number of malnourished people, this block of fragile countries witnessed the most rapid progress in the percentage of malnourished people. Central Africa features a disturbing trend, as it is the sub-region which witnessed considerable spike both in the number and proportion of malnourished people. Southern Africa, on the other hand, witnessed a mixed outcome, with the sub-region recording a reduction in PoU, while reporting a slight increase in terms of the number of undernourished. On the other hand, West Africa witnessed reductions both in terms of number and PoU.

Sub-Saharan Africa is acknowledged with the highest PoU globally, particularly in the last two decades. However, the trend declined steadily from 32.7 to 24.8% (FAO 2013).

The FAO reported that in the period 1993–2000, an average of 15 sub-Saharan countries witnessed food crisis every year, with the number climbing to about 25 countries after 2001 (FAO 2008). From 2005 onward, a core set of about twenty countries were repeatedly listed and twelve other countries appear occasionally, as sub-Saharan Africa accounted for, on average, 60–70% to FAO Global Information and Early Warning System (GIEWS) world list. (These countries were reported with 'hunger hotspots', where a considerable proportion of the people is severely undermined by persistent or repeated food and nutrition insecurity due to inadequate income to address chronic food shortages).

In respect of geographical distribution in sub-Saharan Africa, the FAO report indicated that most of the hunger hotspots are found in East Africa (34%), where all countries but one in the sub-region (Rwanda) required external aid, and in West Africa (30%), where two-thirds of countries feature annually or occasionally on the GIEW's list. The last tier, according to the report, is split between Central and Southern Africa, with 18% each. The FAO report further reveals that between 2005 and 2009, 16 countries in a sample of 46 African countries can be classified as food secure, as they did not witness any food crisis that required emergency intervention. In total, they harbor 350 million people, or 40% of the continent's overall population.

Overall, various studies reveal that across sub-Saharan Africa, food crises are particularly associated sustained localized insecurity, and are consequently more frequent (57%) than crises arising out of widespread lack of access (23%) or an exceptional reduction in the total production/supply (20%) (UNECA 2009). Two of three countries in crisis were reported to be consistently in need of external assistance and the rest on an occasional basis. Also, almost all the food crises in Central Africa were reported to be particularly associated with localized food and nutrition insecurity, as were most of the crises in Eastern Africa was also reported to feature widespread lack of access. At 53% of the cases, this is acknowledged to be more than twice higher than the regional average and more than five times the level of East Arica (10%), while it is negligible in Southern and Central Africa. Exceptional shortfall in food production/supply was reported in the case of Southern Africa (80%), according to the UNECA report.

In a report on Africa's food and Nutrition security, the FAO (2020a) reveals the global PoU stayed at 10.8% over 2017 and 2018, with 822 million undernourished people in 2019, up from 812 million in 2017 and 797 million in 2016. The report also reveals that the PoU in Africa declined from 24.5% in 2000 to 18.5% in 2014, but began to trend upwards, increasing to 20% of the population, or 256 million people. However, in sub-Saharan Africa, the trend was more sobering, with 239 million people living in food and nutrition insecurity, or 22.8% of the population in 2018, up from 232 million in 2017.

It is acknowledged that the greatest deterioration in the number of undernourished people between 2014 and 2018 emerged in Eastern and Western Africa, with the largest number living in Eastern Africa. In Northern Africa, there was a rise in the number of malnourished people, increasing from 16 to 17 million from 2014 to 2017, while in southern Africa, the number rose by 600,000 people over the same period.

An analysis reveals an increase in the prevalence of the undernourished over the period 2014–2017, while it has slowed in recent years. The rise in the PoU was highest in Western (3.4%) and Central Africa (1.9%), while southern Africa's PoU rose between 2014 and 2017, but declined between 2017 and 2018. On the other hand, in Eastern Africa, the rise in the PoU recorded a slower pace, compared to that of Western and Central Africa regarding the number of the malnourished.

3.2 Factors Contributing to Food and Nutrition Insecurity in Sub-Saharan Africa

The major causes of food insecurity in sub-Saharan African can be categorized into two broad groups (UNECA 2009): natural or human driven—i.e. socio-political hazards- (e.g. war or conflict-prone crises), and disasters that are largely driven by macro-economic problems. The latter often results from internal factors, including conflicts emerging from land-based resources, or collapsing public health infrastructure, which triggers such infectious diseases as tuberculosis and HIV/AIDS. On the other hand, macro-economic externalities include the loss of a country's export earnings, or a dramatic spike in the prices of imported food commodities.

The FAO's Global Information and Early Warning System (GIEWS) list reveals the causes of hunger in sub-Saharan Africa are driven by conflict related events (45%), followed by climatic and weather hazards (38%), as well as socio-economic factors (26%). Further, the study reveals that more than 50% of the socio-economic challenges and 33% of the weather-related food emergencies are correlated with socio-political factors. Indeed, conflicts and wars, as well as related social instability in the region are acknowledged the major determinants of famine, given their potential to destroy socio-economic infrastructure and displace populations.

Post-election violence in West Africa was attributed to the disruption of peace and the consequent displacement of large population segments, in a development that also undermined trade and livelihood prospects in Cote D'ivoire, as well as neighbouring land-locked countries, whose goods are moved through the Port of Abidjan, is a case in point. The March 2012 coup d'état in Mali, and the civil war that followed, displaced populations in neighbouring Senegal, Burkina Faso, Mauritania and Niger. In the Horn of Africa, food insecurity has taken a huge toll in the drought-striken pastoral areas of Kenya, Somalia, Ethiopia and Djibouti. The 2010–2012 droughts, in the opinion of experts, is the worst in 60 years, driven by sustained lack of precipitation, precipitating aridity. The droughts considerably undermined vegetative cover throughout the sub-region and undermined pastoral land, fuelling crop failure, as well as the loss of livestock on a massive scale. The droughts also triggered a wave of humanitarian crisis, accompanied by heavy economic lives, with 13 million people in need of emergency, food and livelihood assistance in Ethiopia, Djibouti, Somalia and Kenya. Indeed, East Africa is threatened by "double-dip" hunger crisis, with the potential to plunge millions into hunger and malnutrition.

In the Sahel region of West Africa, a new food and nutrition insecurity emerged, undermining millions in 2012, driven by a combination of rising grain prices, and drought, decreases in remittances, displacement of population, environmental degradation, endemic poverty and vulnerability. More than 16 million people are humbled by food and nutrition insecurity, while more than one million children below five years are at risk of acute undernourishment. Indeed, the sub-region is undermined by underdevelopment challenges, as well as multiple droughts in recent years, which have left the population vulnerable to shocks. The development has been exacerbated by inadequate rainfall and crop production shortfalls in 2011, resulting in inadequate livestock fodder and food in the Sahel, where many humbled families are struggling to recover from the 2009/10 food crisis. Of the 16 million people at risk, 8 million faced severe food and nutition insecurity requiring emergency food intervention in 2012 and the years that follow.

4 Fostering Food Security Framework in Sub-Saharan Africa: The Emergence of Drought Tolerant Maize in Africa

4.1 Preamble

Cereals are acknowledged with pivotal roles in Africa's food and nutrition security. They also play a major role in food supply in Sub-Saharan Africa, however, production generally lags behind population growth rates across the sub-continent (FAO 2006). It is interesting to note that countries that have engaged in concerted efforts to increase their cereal production and export agricultural products have generally translated these outcomes into food and nutrition security. In order to bridge the food demand gap, sub-Saharan African countries have had to augment domestic production with increasing imports: more than 25% of cereal consumption is currently imported (compared with 5% in the late 1960s). In fact, the level is much higher in low-income African countries, triggering trade balance challenges and high debt, for which these imports are unsustainable. Consequently, these countries have had to depend on food aid imported from foreign donors.

In the past several decades, Africa's food security has been undermined by persistent droughts, featuring low and irregular rainfall (AU 2006). The sub-region of the continent that is most vulnerable to incessant droughts is the Sahelian agro-ecological zone. The livelihood of the people in the zone revolves on cereal production and pastorialism. However, cereal production is not limited to the Sahelian zone. The wet, tropical agro-ecological zone also features cereal production, which has also been undermined by irregular rainfall. Adequate water supply is critical to Africa's agriculture because of the region's dependence on rain-fed agriculture. Therefore, it became imperative to develop a unique cereal crop that is adaptable to Africa's diversified agro-ecological zones. It is against this backdrop that the Drought Tolerant Maize in Africa (DTMA) emerged in, 2006, as an innovative tool to tackle the perennial food and nutrition security challenges in Sub-Saharan Africa.

4.2 The State of Maize Production Trends in Sub-Saharan Africa

Maize, or corn, has emerged as the most popular cereal crop in Sub-Saharan Africa, which together with rice and wheat, remains one of the three most important cereal crops in the world. The crop has become popular among farmers across the sub-region, with production in West and Central Africa alone increasing from 3.2 million in 1961 to 8.2 million metric tonnes in 2005. The rapid surge in the land area planted to maize translated into increased production from 2.4 million metric tonnes in 1961 to 10.6 million metric tonnes in 2005. However, the rate of production in the sub-region lags behind the trend in developed economies. While the average productivity of maize in developed countries have potentials to reach 8.6 tonnes/ha, production per hectare in Sub-Saharan Africa is estimated at a paltry 1.3 tonnes. In developed market economies, maize is largely utilized as livestock feed, as well as raw materials for industrial products. This is in sharp contrast to Sub-Saharan Africa, where maize is used primarily as food for human consumption, accounting for 30–50% of low income household expenditure in Southern and Eastern Africa. While the African continent accounts for 6.5% of maize production in the world, Nigeria has emerged with the highest production on the continent, followed by South Africa (IBP 2014). However, in an affirmation of inadequate production of the cereal crop in the region, the continent imports 28% of the required stock of maize from outside the outside world.

Indications are that maize production remains a major livelihood activity of many farmers in sub-Saharan Africa. FAO (2016) database reveals that maize cultivated across the sub-region is estimated at 35 million ha, translating to about 26% of the total cropping area in the sub-region; varying from 11% in Mali to 46% in Zambia. However the proportion of maize to other crops is largest in Southern Africa in comparison to Eastern Africa, where it is ranked first or second; and in West Africa, where it is ranked either first, second or third. The FAO database also reveals that the average family size engaged in maize cultivation in sub-Saharan Africa was about 7.8, in a development that is hardly evenly distributed across the region. Indeed, there was considerable sub-regional variation, with family size in West Africa remaining largest, compared to Eastern and Southern Africa.

4.3 The Emergence of Drought Tolerant Maize in Africa

The Drought Tolerant Maize in Africa was launched with the aim of mitigating drought and other stresses undermining maize production trends in sub-Saharan Africa. The project, which aims to foster sustained increases in maize yields by a minimum of one ton per hectare under mild drought conditions, with 20–30% rise in current farm yields, seeks to bring economic benefits to 40 million people in 13 African countries. This is expected to be extended to other countries in the region.

With the collaboration of farmers, researchers, extension specialists, seed producers and non-governmental organizations, the project is jointly developed and implemented by the International Maize and Wheat Improvement Centre (CIMMYT) and the International Institute of Tropical Agriculture (IITA), in close collaboration with National Agricultural Research Systems in participating African Countries (Doering 2005; CIMMYT 2013). Maize is grown on about 33 million of the total 194 million hectares of cultivated land in sub-Saharan Africa, becoming the sub-region's most popular food crop. Small holder farmers in 46 countries, with a combined population of 553 million, produce maize under various and divergent agro-ecological zones and socio-economic conditions. Sixteen of these countries plant 25–65% of their total cultivated land to maize. With only 1.8 tons of grain per hectare, current average maize yields in Africa lags far below the crop's genetic potential. The causes of the low yield include drought, degraded and infertile soils, diseases, insect pests and weeds, as well as limited access to such technologies as improved seeds and fertilizers. Also, maize cultivation in Africa is primarily rain-fed; thus, depending on the region's increasingly unreliable precipitation. An estimated 40% of Africa's maize area is vulnerable to occasional drought stress, with yield loses of 10–25%, while 25% of the maize crop suffers frequent drought, with loses as high as 50% of the harvest. Indeed, total crop failure is common with severe droughts (CIMMYT and IITA 2011).

4.4 Dispersion of Drought Tolerant Maize in Africa: Progress and Prospects

Since 2007, the Drought Tolerance Maize in Africa (DTMA) has been dispersed across Sub-Saharan Africa, with a great deal of success. About 60 drought tolerant hybrids and 57 open pollinated varieties have been distributed to small scale farmers in the sub-region. These varieties meet or exceed the productivity of widely sown commercial seeds when rains are regular and dependable, and yield 20–30% more under moderate drought conditions (CIMMYT 2013). In addition to drought tolerance, the new varieties and hybrids also feature such additional qualities as resistance to major diseases, as well as superior milling or cooking qualities (Bemire et al. 2010).

Dispersion of DTMA has continued with rapidity in the sub-region. During the 2011–12 cropping season, about 29,000 tons of seeds was produced, enough to grow more than 1.1 ha; with benefits to about 2.9 million households or 20 million people. Estimates are that the production of drought tolerant maize in Africa reached 60,000 tons by 2016. CIMMYT and IITA, together with other stakeholders, have engaged government officials in the region in policy dialogue aimed at fast tracking varietal releases and fostering competitive seed markets to generate widespread access to quality seed at favourable prices. In order to ensure farmers' access to a combination of robust products and services, DTMA has coordinated various capacity-building platforms for various stakeholders, including technicians, maize breeders, extension workers, seed producers, farmer groups and non-governmental organizations. It is the opinion of experts that with successful dispersion of DTMA in the region, resource-poor farmers and their families stand to benefit enormously. The project also has the potential to limit importation of grains in the DTMA countries, conserving scarce foreign exchange earnings.

In an empirical study on suitable drought tolerant maize genotype planted in the Southern Guinea Savanna (SGS) agro-ecological zone of Nigeria, Takim (2017) evaluated the performance of DT hybrid and Open Pollinated Varieties (OPV), employing farm trials under different localities. Data collected for the study were sourced from field trials conducted between 2007 and 2014 on different maturity groups among open pollinated varieties and hybrids, which were selected and analyzed. Findings reveal that grain yield across the agro-ecological zone varied, ranging from 5029.69 to 7165.98 kg/ha for drought tolerant open pollinated varieties, while hybrids yielded between 9234.77 and 11,955.18 kg/ha. The location of the agro-ecological zone for the field trials is significant, accounting for about 70% of yield differences, indicating the variability of locations in the southern Guinea Savanna region, according to Takim (2017).

The dispersion of DTMA across Sub-Saharan Africa has assumed a rapid dimension in recent times; with 233 varieties, including about 200 district drought tolerant maize varieties, which were released to target countries by January, 2016. The novel varieties were adapted to various agro-ecological zones in each of the target countries, most of which have been commercialized. In addition, all of them are tolerant to parasitic weed, ***striges hermonthica*** and are nitrogen—use efficient, among other things.

It is noteworthy to state that the largest areas planted to drought tolerant maize varieties were in Nigeria (>23%), Malawi (~22%), Benin (~22%), Zambia (>10%) and Uganda (~20%). Estimates also reveal that four of the maize area planted to drought tolerant varieties in 2015 have risen beyond 100,000 ha, namely, Sammaz 15 in Nigeria, pan53 in Zimbabwe, BH661 in Ethiopia, and ZM23 in Angola. In addition, a total of 27 varieties were dispersed across 10 of 13 countries, each occupying >10,000 ha. At the same time, a total of 19 varieties were cultivated in 9 countries, each covering >5000 ha.

The rapid adoption of DTMA in sub-Saharan Africa is not without considerable constraints, which vary among countries. The most challenging obstacle in Benin, for example, relates to the dearth of improved seeds, which is also a binding constraint in Ethiopia, Nigeria, Zambia, Tanzania and Uganda. However, high cost of seeds and consumer preference are two of the most important constraints in Malawi, while lack of resources is the single most challenging obstacle in Mali, according to DT maize report.

5 Summary, Recommendations and Conclusion

5.1 Summary

Food security is a contemporary development challenge in developing countries, particularly in sub-Saharan Africa, where more than 234 million people or 22.8% of its population were living with food and nutrition insecurity in 2018. Concerns about accessibility to sufficient food emerged in the early 1970s, with parts of the developing world featuring chronic malnourishment. The widespread concern drove the issue of food insecurity to the global limelight, with the emergence of the World Food Summit in 1996. Also, in 2001, the Millennium Development Goals were embarked upon by the international community, with a key goal aimed at reducing by half the proportion of the global population living in hunger by 2015. Sub-Saharan Africa has emerged as the most vulnerable region, where a significant proportion of the population is prone to suffering chronic hunger and undernourishment. The situation was exacerbated by the spikes in the global prices of staple foods in 2008–2010, triggered by the global financial and economic crises. While the trend with food insecurity in the sub-region has subsided in recent times, many countries are still facing the threat posed by it. In the light of widespread concern against food security in Sub-Saharan Africa, an international forum, spearheaded by CIMMYT and IITA, in 2006, launched the Drought Tolerant Maize in Africa (DTMA), as an innovation aimed at fostering food security in the region. The hybrid seeds of DTMA have been dispersed across 13 countries in the sub-region, with socio-economic benefits to resource-poor farmers. The crop has considerable potential to address the sub-region's food deficit, while it is primed to conserve funds that would otherwise be set aside to finance importation of maize in future (Badu-Apraku et al. 2008).

5.2 Recommendations

This section presents policy recommendations aimed at fostering food security in sub-Saharan Africa, which are as follows:

- **Transform the Agricultural Sector**: The agricultural system in many countries south of the Sahara is largely dysfunctional, characterized by lack of access to novel technologies. Policy makers across the region therefore need to transform the key sector through a sustained programme of economic reform agenda, grounded in modernization and the investment in novel technologies, which should become accessible to small scale farmers.
- **Develop the capacity of National Agricultural Research Institutes in the Region**: Several Agricultural Research Institutes across the region are underfunded and lack capacity to undertake robust research programmes. Therefore,

there is need to increase the level of investment in the research institutes to boost collaboration and with researchers in other regions of the world.

- **Revive Agricultural Extension Agencies**: Agricultural extension agencies in the public sector have largely become moribund in the aftermath of the Structural Adjustment Programme (SAP) in the 1980s. However, in order to increase the capacity of farmers to employ novel agronomic practices, there is urgent need to review the activities of extension agencies to disseminate best practices associated with farming techniques. This holds the key to increasing agricultural productivity, which is lowest in the region, in comparison with other developing regions in the world.
- **Reserve 10% of the National Budget for the Agricultural Sector**: In line with the pledge of African leaders aimed at meeting the Millennium Development Goals (MDGS), African leaders are committed to reserve 10% of the annual budget in their respective countries for the development of the agricultural sector. However, only a small fraction of countries has implemented this pledge. Policy makers in Africa are therefore advised to implement this pledge as a key step in the transformation of the agricultural sector.
- **Adopt Poverty Reduction Strategies**: Development practice in Sub-Saharan Africa should focus on resource-poor farmers, who account for the bulk of the food supplied to the market. A conscious effort aimed at providing social and physical infrastructure to transform rural livelihoods should receive priority attention of policy makers. Such social services as education, healthcare, electricity, water supply, road networks should become accessible to the poor living in rural areas in order to escape from the poverty trap.
- **Deepen the Dispersion of DTMA**: Currently, the Drought Tolerant Maize in Africa is available only in 13 countries in the region. Concerted efforts should be made to make the hybrid seeds of DTMA available to farmers in other countries across the region in order to disperse the socio economic benefits associated with the new crop.

5.3 Conclusion

Food security is a global issue, particularly in developing countries. It remains a challenge in sub-Saharan Africa, where chronic hunger is a threat to a significant proportion of the population. In the past couple of decades undernourishment has become a serious development issue in the sub-region, tasking the effort of policy makers in several countries. A variety of reasons has been blamed for food insecurity in the region. These include natural and socio-economic factors. In the former, persistent drought, driven by irregular rainfall, has undermined food production, particularly in the Sahel. In the latter, incessant conflicts trigger instability in several countries, often leading to armed conflict. And the resultant humanitarian crises unsettle people from their livelihoods. This development has undermined food production in severely afflicted countries in the region, with serious consequences for food security. However, in the most recent times, food insecurity has declined in several countries across the region. At the same time, the Drought Tolerant Maize in Africa has emerged as an innovative mechanism, with the aim of attacking food insecurity as menace in 13 countries in sub-Saharan Africa, with considerable socio-economic benefits, which will soon become available across the region.

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Climate-Smart Agriculture Approaches and Concepts for Food Systems Transformation in Sub-Saharan Africa: Realities and Myths

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1 Introduction

CSA as a concept has gained momentum as a sustainable solution to transform and reorient agriculture under the occurrence of climate change (Adolph et al. 2020; Schaafsma et al. 2018). Presently, climate change threatens and will continue to devastate agricultural systems globally (Jansson and Hofmockel 2020; Zakaria et al. 2020; Konapala et al. 2020). With the current severity of climate change, CSA aims to; (i) sustainably increase agriculture productivity, raise farmers' incomes, ensure long-term food security, (ii) enhance sustainable agriculture adaptation to climate impacts, and (iii) reduce agriculture GHG emissions (Zakaria et al. 2020; Adolph et al. 2020).

In the CSA discourse, major contestations include; (i) considering which practices and technologies as CSA and (ii) uncertainty of trade-offs of CSA are issues that require attention (Andrieu et al. 2020; Partey et al. 2018). Despite these contestations, several CSA innovations, tools, and policies already integrated with indigenous activities and approaches have helped farmers build climate resilience and increase

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productivity (Martey et al. 2020; Branca et al. 2020). Also, the advancement of new technologies, approaches, tools, and policies through research is helping achieve CSA goals through field demonstrations and on-farm trials (Zakaria et al. 2020; Partey et al. 2018).

In SSA, many agricultural intensifications options; including drought-tolerant crop and livestock breeds, small-scale irrigations, agroforestry, crop diversification, conservation agriculture, weather-based insurance, and soil fertility management, are promoted as CSA practices and technologies (Branca et al. 2020; Clay and Zimmerer 2020; Partey et al. 2018). The positive outcomes of these practices are relevant in advancing agricultural progress in SSA under increasing climatic stress. Nonetheless, CSA can only be efficient and effective with maximum societal impacts if the practices are adopted by many farmers globally (Etwire et al. 2020; Andrieu et al. 2020). The impacts of CSA, mostly on the vulnerable, require strengthening efforts at institutional levels to broaden adoption. The uptake of CSA in SSA stays low and unsatisfactory impeding sustainable development (Andrieu et al. 2020; Etwire et al. 2020; Partey et al. 2018). Context-specific CSA options can promote efficient up-scaling and out-scaling of CSA while enhancing the incorporation of CSA into international negotiations. In this paper, we discuss; (1) the need for CSA in SSA (2) potential CSA practices and their successes in SSA (3) Challenges to CSA implementation, and potential areas for improvement, (4) sustainability and gender differentiation in CSA.

2 Materials and Methods

2.1 Data and Analysis

A content analysis approach was employed in collecting and presenting information about CSA in SSA. The content analysis approach allows for in-depth assessment of information and identification of patterns in both printed and recorded communications (Lindgren et al. 2020). For this study, a detailed review of journal articles, reports, and web content on CSA was conducted. The approach was employed because CSA is a growing concept in SSA, thereby providing an opportunity to assess the myths and realities through currently available content information. Information on the myths and realities of CSA in Africa is imperative to influence practical action and create an understanding of the dynamics of CSA implementation. In conducting the content analysis, important issues considered included practices considered as CSA in SSA, successes and failures of CSA practices, challenges of CSA implementation, CSA contribution to sustainability and gender inclusion. Subsequently, interviews were conducted among farmers who have participated in CSA implementation. The interviews sought to promote a bottom-up policy of CSA implementation by understanding CSA from the farmers' perspective. A total of thirty farmers (30) were included in the interviews, and both male and female farmers participated.

The interviews were interpreted and used to support the narratives from the content analysis. The interviews were conducted in five (5) SSA countries, thus, Ghana, Benin, Togo, Nigeria, and Burkina Faso. The inclusion of these countries was based on the availability and readiness of farmers to participate in interviews. Aside from farmers, local government officials, agriculture extension officers and representatives from ministries of food and agriculture of the various countries were interviewed to provide a policy perspective on CSA implementation. In the study, participants (P) is used to represent the interpretation of information from an interviewee/participant.

2.2 Contextualizing CSA in SSA

CSA has seemingly been controversial in its role to address multiple objectives (Andrieu et al. 2020; Clay and Zimmerer 2020). CSA is heavily criticized as a single-sided agenda as it continuously neglects mitigation issues (Westermann et al. 2018; Aggarwal et al. 2018). The clarity of CSA can be achieved with data-based information on mitigation goals and building strong synergies for adaptation and mitigation. Also, the main global contributors to climate change are encouraged to consider co-opting CSA practices (Pimbert 2015). For others, CSA has an inadequate focus on the agro-ecological and socio-technical practices employed by farmers towards climate change adaptation (Saj et al. 2017). Across SSA, mainstreaming CSA into national development plans has been slow yet progressive (Clay and Zimmerer 2020; Etwire et al. 2020; Partey et al. 2018). Different CSA projects coordinated by national governments, development partners, civil society organizations, and sometimes a combination of all have targeted rural agriculture transformation. For instance, agroforestry in Niger improved the livelihoods of about 1.25 million households and enhanced carbon sequestration (Pretty et al. 2011). Maize-legume intercropping supported yields improvement in Malawi (Ngwira et al. 2012). Climate-smart villages in *Yatenga* (Burkina Faso), *Lawra-Jirapa* (Ghana), *Borana* (Ethiopia), *Wote,* and *Nyando* (Kenya) by the World Bank and FAO supported rural livelihoods transformation (Wattel and Asseldonk 2018).

3 Results and Discussion

3.1 Practices (Some) Promoted as CSA in SSA

The literature shows several CSA options promoted across different countries in SSA with their contribution to adaptation and mitigation. Some of the practices are improved practices from indigenous knowledge that farmers have already been engaged in spontaneously. Others were planned CSA options from new technologies introduced to farmers. We discussed nine (9) common practices found in the literature.

3.1.1 Agroforestry

Agroforestry is an extensive agricultural activity in SSA that aims to increase tree cover, above and below-ground biomass, including soil carbon (Partey et al. 2018). Agroforestry activities, together with agro-silviculture with tree species (*Magnifera indica, Anacardium occidentale, Tectonagrandis* teak, and *Maringa oleifera*), are grown on croplands in Ghana, Mali, Niger, and other several SSA countries (Andrieu et al. 2020; Wattel and Asseldonk 2018). Boundary and hedge tree planting not to mention borders and roadsides create favourable microclimates for crops and serve as windbreaks, and also stabilizes the soil. These systems increase soil productivity through increased litter inputs, soil nutrient availability, improved green manure and fallowing practices. Trees provide fodder that serves as an integral feedstock for livestock. The integration of agroforestry in cropland and livestock builds farmers' adaptive capacity, improves yields, and promotes climate change mitigation (Clay and Zimmerer 2020). Apart from agro-silviculture, farmer-managed natural regeneration (FMNR) remains a relevant agroforestry practice in SSA (Kibru et al. 2020; Iiyama et al. 2017). In SSA, FMNR reduces desertification, improves soil productivity, and provides biomass for household energy (Garrity et al. 2010). An interviewee elaborated;

> Planting trees on the farm has helped to improve crop productivity. For the past three years, I (farmer) have received training from different organizations on planting different species of trees on my farm. The trees are planted around the farm on the boundaries. Now, I (farmer) harvest fruits from some of the trees planted for sale and household use (P04, Benin).

3.1.2 Integrated Nutrient Management (INM)

Soil degradation and nutrient depletion are major threats to SSA's agriculture (Garrity et al. 2010; Wattel and Asseldonk 2018). The soil in some countries in SSA has limited nutrients with low potency leading to the rapid decline of productivity once cropping commences (Kibru et al. 2020; Iiyama et al. 2017). Integrated nutrient management (INM) as a CSA option is the optimization of organic, inorganic, and biological components in an integrated manner to improve soil fertility and plant nutrient supply (Wattel and Asseldonk 2018). INM is best workable with context-specific biophysical resources, economic feasibility, and social acceptability. It has been recognized that SSA soils are more responsive to INM as compared to a single nutrient source (Clay and Zimmerer 2020; Wattel and Asseldonk 2018). The use of only N and P fertilizers is discouraged in SSA as they decrease soil organic content, cause acidification, decrease base saturation, and cause a large increase in exchangeable aluminium (Holden 2018). Organic intensification measures including manure and crop residue application on farms have been established to improve soil fertility (Beeby et al. 2020). Nonetheless, the limited availability of these sources (Wattel and Asseldonk 2018), competing uses (Beeby et al. 2020), and price or financial risk challenge farmers' capacity to fully employ these measures. Therefore, it is imperative to consider multiple sources of nutrients.

3.1.3 Crop Association/Intercropping

Growing crops or genotypes together in a whole growing season is a functional diversity mechanism used in an agroecosystem (Brooker et al. 2016). Additionally, intercropping has significant benefits, including; enhancing crop rate of production, simultaneously decreasing the risk of total crop production, and weed control (Clay and Zimmerer 2020; Wattel and Asseldonk 2018). In SSA, simultaneously growing crops engenders the diversity of grower production, and/but expands and increases food options for households (Partey et al. 2018). For example, a study on the efficacy of intercropping in Africa showed that intercropping can increase crop yields by 23% when appropriately implemented (Himmelstein et al. 2017).

Intercropping has, however, been less promoted by developmental projects in SSA due to difficulties in choosing appropriate combinations, complexities of selecting intercropping combinations, limited information on best crops to associate, and inadequate complementary inputs such as herbicides and field access difficulties (Himmelstein et al. 2017; Brooker et al. 2016). In some SSA countries, there is a huge gap in technical reports regarding the effects of intercropping on yield and profitability that limit the motivation of development agencies.

> Several farmers in this area (semi-arid Ghana) are engaged in intercropping. At first, we (farmers) used to intercrop with maize, millet and sorghum but from training and demonstrations received from organizations, cowpea, Bambara beans and vegetables are now included in the intercropping. The residue from the Bambara beans and cowpea are used for preparing compost (P14, Ghana).

3.1.4 Soil Fertility Management (Composting and Mulching)

Mulching is a key strategy to retain moisture and create humus. Mulch materials can be cardboard, paper, seaweed, leaves, degraded manure, old cotton or wool clothes, plastic sheets, sawdust, and old carpets (Masvaya et al. 2017). Mulching is usually done at the beginning of the vegetative season and repeated as much as necessary. The initial purpose is to help retain the heat of the soil, which allows sowing and early transplanting of certain crops and stimulates faster growth. As the season progresses, the clogging has different effects on the ground, including; stabilizing the temperature, reducing evaporation, preventing weeds and pests from germinating due to lack of sunlight, and adding nutrients to the soil due to the decomposition of the material. Compost for instance converts animal and plant wastes to humus through chemical and biological decomposition. On records long fallowing, burning and grazing are the traditional ways to utilize available biomass in SSA (Masvaya et al. 2017; Rodriguez et al. 2017). Compost and mulch (with crop residues, weeds and legumes) have historically increased crop production, reduced soil erosion, and leaching (Rodenburg et al. 2020). A study by (Roose and Barthes 2019) in West Africa, established that mulch and compost reduced carbon losses, erosion, and leaching between 10 and 100 kg C ha^{-1} in soils depending on annual rainfall and vegetation cover.

3.1.5 Tillage Management (No/Reduced Tillage)

No or reduced tillage limits disturbance and allows for more residue to remain in soil (Zakaria et al. 2020; Partey et al. 2018). Economically, it directly saves the farmer machinery cost, fuel and labour (Branca et al. 2020). Environmentally, crop residue prevents soil erosion, thus, conserving the valuable topsoil and soil. Minimum/no-tillage reduces disturbances on soil microbial organisms, increasing their numbers for better soil aeration and soil structure improves in the absence of heavy machinery. Tillage management also reduces the amount of fossil fuel use on farms thereby reducing CO_2 emissions from agriculture (Clay and Zimmerer 2020). In rural farms in Malawi, no-till increased soil water content by (0–60 cm) and reduced sediment runoff compared to deep tillage (TerAvest et al. 2015). In humid and sub-humid regions of Africa, no-tillage with crop residue mulch helps to control soil compaction. However, no/reduced tillage limits the mixture of soil amendments such as limestone leading to stratification of soil nutrients and pH (Liebenberg et al. 2020).

3.1.6 Residue Management (Residue Incorporation)

Crop residue is the most readily and available form of crop biomass for farmers. The biomass that remains after harvesting crops is an important source of soil organic matter for agricultural soils (Radicett et al. 2020). Common crops grown in SSA including maize, beans, cowpea, sweet potatoes, rice, wheat, and groundnuts, have high generated residues (Adolph et al. 2020; Schaafsma et al. 2018). The incorporation of crop residues in farms helps to improve microclimatic conditions that optimize decomposition and mineralization of organic matter, enhance soil carbon sequestration and prevent soil erosion. Some studies in SSA (Zakaria et al. 2020; Konapala et al. 2020; Andrieu et al. 2020; Partey et al. 2018) established positive outcomes of crop residue retention on soil moisture, soil quality, and soil organic matter. For instance, higher crop productivity was found in residue retained areas in Ghana, Benin, Mali, and Cote d'Ivoire whereas lower productivity was obtained in residue removed areas (Wattel and Asseldonk 2018). Residual retention has shortcomings, especially in areas where farmers have inadequate knowledge and understanding in implementing the practice. Inappropriate introduction of residue retention or incorporation could result in nitrogen immobilization, waterlogging and decreased soil temperature (Turmel et al. 2015).

3.1.7 Improve Varieties (Crop and Livestock)

The use of scientifically designed advanced varieties to meet area-specific needs and conditions has gained momentum in SSA (Haggar et al. 2020; Partey et al. 2018; Wattel and Asseldonk 2018). Traditional crop varieties are attributed to low yield due to their vulnerability to drought, heat, diseases, and other climatic stressors (Partey et al. 2018; Wattel and Asseldonk 2018). On the contrary, improved varieties are capable of offering higher and stable yields, and are also resistant to drought, diseases, and pests. The growing interest of SSA in improved varieties has resulted in collaborations to develop improved varieties such as new maize varieties (Grace and ZM521) for smallholder farmers in South Africa (Setimela 2017; Sibanda et al. 2016). Also, the Improved Maize for African Soils (IMAS) project) has developed drought-tolerant and insect-protected maize varieties for adoption by smallholder farmers across SSA (Setimela 2017). Recent studies (Partey et al. 2018; Wattel and Asseldonk 2018) in SSA have established positive outcomes of improved varieties in different countries of the region. Jaleta et al. (2018) evaluated and established that improved maize varieties enhanced household food security in Tanzania. In Kenya, Sinyolo (2020) found using hybrid maize seed positively influenced incomes and assets, poverty, and inequality reduction.

3.1.8 Organic Fertilization

A practice commonly categorised as part of conventional agriculture is synthetic fertilizer use on agricultural soils (Leitner et al. 2020). Synthetic fertilizers are artificial soil inputs derived from the composition of chemicals (nitrogen, phosphorous, potassium, calcium, magnesium, etc.) and inorganic substances (Mosier et al. 2013). Synthetic fertilizers supply nutrients to the soil but at a high risk. The high mineral salt content in synthetic fertilizers can kill crop roots and soil microbes and reduce organic matter content in soil (Leitner et al. 2020; Mosier et al. 2013). CSA embraces the use of internal organic resources including green manure, compost and biological pest control (Partey et al. 2018; Wattel and Asseldonk 2018). Smallholder farmers in SSA mainly derive manure and compost from their livestock and feedlots or a neighbouring farm. Higher crop yields have been observed under organic-oriented fertilization (Epule et al. 2015). In Gambia, Madagascar, and Sierra Leone, studies have shown that average rice yield grown under the inorganic fertilization method is lower than observed under organic fertilizer rice intensification (Partey et al. 2018; Wattel and Asseldonk 2018; Epule et al. 2015).

> The government organic fertilizer project has provided incentives for the preparation and utilization of organic fertilizer. For instance, compost is provided by the government to support organic farming. Farmers have also learned to prepare their own compost and minimized the use of synthetic fertilizer (P06, Burkina Faso).

3.1.9 Drip Irrigation

Unavailability of safe and quality water in most areas of SSA is a limitation to the efforts of achieving the UN Sustainable Development Goals (SDGs) of reducing extreme poverty and malnutrition (Jansson and Hofmockel 2020; Zakaria et al. 2020; Konapala et al. 2020). Likewise, estimations indicate that about 80% of the rural population in SSA strongly depend on water for both domestic and agricultural purposes (FAO 2018). Additionally, these areas experience low accessibility to freshwater needed to produce the biomass (Partey et al. 2018; Wattel and Asseldonk 2018). Nonetheless, recent studies (Nigussie et al. 2020; Nakawuka et al. 2018) have shown through supplementary irrigation, there can be progress with substantial water productivity. Ghana, Kenya, Zimbabwe, and South Africa have recorded an increase in the usage of simple drip irrigation kits (Friedlander et al. 2013).

Drip irrigation supplies water directly to the roots of crops to improve soil moisture, increase yield outcomes, and promote water savings to about 40–80% compared to conventional irrigation (Nigussie et al. 2020; Nakawuka et al. 2018). For instance, in Northern Mali, drip irrigation led to an increase in access and capacity of rural farmers' income and social insurance (Dillon 2011). Likewise, in Northern Senegal, all-year-round vegetable farming through canal irrigation improved the availability of nutritional options for households (Diallo et al. 2020; Van den Broeck et al. 2017). In most communities, drip irrigation practices empowered women in northern Senegal to utilize solar-powered pumps, rather than hauling water by hand in rural off-grid areas (Diallo et al. 2020; Van den Broeck et al. 2017). Given this, government programs, private purchases, and non-governmental organizations (NGOs) initiatives should facilitate access to low-pressure drip irrigation kits to farmers.

> Drip irrigation is currently helping us (farmers) to cultivate. There is prolonged drought, and inconsistent rainfall. Drip irrigation is easy to practice and less expensive. Female farmers can engage in vegetable farming through drip irrigation. Women supply vegetables which are cultivated mostly from drip irrigation to supermarkets and other places. (P18, Mali).

3.2 Limitations to CSA Implementation in SSA

As CSA presents several positive outcomes in transforming agriculture in SSA, it is important to up-scale and out-scale the CSA options with higher efficacies. More importantly, SSA farmers need to embrace CSA and efficiently implement viable options. Efforts have emanated from different directions to incorporate and make CSA a progressive approach. Nonetheless, several setbacks limit the operationalization of CSA. Aggarwal et al. (2018) attributed the low adoption of CSA to inadequate empirical evidence on the successes of CSA as a practical solution for agriculture transformation. High dependency of CSA initiatives on donor funding, weak institutions, and inadequate supportive policy strategies also limit CSA implementation in various countries (Ajayi et al. 2018). In this section, we discuss the limitations of CSA operationalization in SSA.

3.2.1 Inadequate Understanding of CSA Concept and Framework

CSA has received criticism for not presenting enough clarity on what exactly constitutes CSA (Andrieu et al. 2020; Partey et al. 2018). Moreover, different stakeholders conceptualized CSA in different ways based on their understanding and available information. Recent literature (Adolph et al. 2020; Aggarwal et al. 2018) calls for the development and implementation of context-specific CSA, but the limitation is inadequate clarity on which practices constitute CSA. Smallholder farmers in SSA countries continue to receive information and training from different sources yet differences in approaches and techniques complicate implementation (Andrieu et al. 2020; Partey et al. 2018).

3.2.2 Marginality of Agro-Ecological Regions in SSA

The different agro-ecologies and heterogeneous socio-cultural and socio-economic factors in SSA impede mainstreaming and implementation of CSA options (Andrieu et al. 2020). At the farm level, outcomes can significantly vary from farmers due to local agro-ecological conditions, institutional framework, household typology, and socio-economic factors (Adolph et al. 2020; Aggarwal et al. 2018). In resolving issues on lagging of scaling CSA options, developing context-specific options is required. Cultural dynamics of what the farmers already know, what they are willing to learn and assimilate, and what is right or wrong in a particular context also influence CSA implementation. CSA options and practices need to be feasible with reality, have the necessary resources and capacity to provide maximum net benefits at minimal risk (Martey et al. 2020; Branca et al. 2020). Concerning improving adoption, a clearer understanding of choices and feasible outcomes guarantees the integration of national and international policies at the farm level.

3.2.3 CSA Mainstreaming into Existing Policy Frameworks

Mainstreaming CSA remains challenging as already existing country-level policies, programs, plans, and strategies were initially developed without CSA reflection (Branca et al. 2020; Clay and Zimmerer 2020; Partey et al. 2018). Given these, the lack of consideration of CSA will require a thorough assessment, review, and adjustments to identify appropriate opportunities in the national, regional policies, plans, programs, and strategies to allow for the mainstreaming of CSA. However, opportunities for such reviews and revisions are hindered by compatibility challenges (Andrieu et al. 2020; Partey et al. 2018). Many African countries are still in the process to link climate change adaptation to national agriculture development plans (Williams et al. 2015).

> CSA is an excellent concept that promotes sustainable agriculture. In Ghana, efforts have been made to mainstream CSA into national policies and promote implementation at the farm level. For instance, Ghana has developed a CSA policy document that provides blueprints

> for CSA implementation. However, mainstreaming CSA is still slow in the country because space has to be created within various sectors to ensure successful mainstreaming. It has been difficult creating opportunities for CSA integration in various national policies (P22, Ghana).

3.2.4 Difficulty in Managing Trade-Offs

Upscaling and integrating CSA presents several trades-off associated with social, environmental, and economic concerns (Etwire et al. 2020; Andrieu et al. 2020). With the expectations of CSA reducing inequalities, improving agriculture literacy, and skills development, CSA has been insufficient in transforming livelihoods and promoting sustainable development (Clay and Zimmerer 2020; Etwire et al. 2020; Partey et al. 2018). Managing CSA trade-offs can result in situational conflicts. In Malawi, irrigated farming on river banks was expected to increase farm revenues but negatively affected siltation mitigation (Schaafsma et al. 2018). Shortage of labour and capital limited farmers in implementing the desired CSA strategy, such as the adoption of soil and water conservation measures, which contributed to the impoverished outturn in Ghana, Burkina Faso, and Malawi (Adolph et al. 2020). In West Africa, farmers are in an emotional conflict as they observed undesirable impacts of CSA, both immediate and futuristic (Adolph et al. 2020).

> Even though CSA is already providing ample benefits, people are thinking about the possibilities of future adverse effects and emergencies. Implementers may concentrate more on the economic aspects of CSA neglecting the equally important other aspects. This may generate environmental footprints which may not be sustainable in the long-term (P12, Nigeria).

3.2.5 Inadequate Financial Investments Towards Broadening CSA Packages

Agriculture transformation and resilience-building require a significant increase in capital investment for climate-smart agriculture (Garrity et al. 2010; Kibru et al. 2020; Wattel and Asseldonk 2018; Iiyama et al. 2017). In SSA, where CSA makes an enormous contribution to climate change adaptation and mitigation, more financial commitments are needed to increase its' implementation (Wattel and Asseldonk 2018). Access to capital for CSA has been a challenge due to low private sector investment, low national government commitments, and other climate-related issues that deserve global responses. The World Bank reports that stakeholders need to examine innovations for financial upgrades while delivering positive climate outcomes for CSA (World Bank 2018). Addressing CSA financial needs can be an opportunity to increase private and public sector funds, strengthen the links between financial institutions, smallholder farmers and SMEs, and build the capacity of both lenders and borrowers.

> Access to finance for the implementation of CSA projects is a challenge. There are many CSA projects the Ministry of Food and Agriculture wants to implement targeting smallholder farmers in rural areas but the funding is inadequate. Proposals have been submitted to raise

funds for these projects but at the international level, it seems difficult with funding for CSA projects (P22, Ghana).

4 Which Lessons for Sustainability?

Our review shows that CSA can help achieve sustainability in developing countries. Studies (Clay and Zimmerer 2020; Etwire et al. 2020; Partey et al. 2018; Thiele 2016) show that CSA incorporates the dominant pillars of sustainability (social, economic, and environmental) in supporting agricultural systems transformation. As revealed in our review, different CSA options promoted environmental sustainability (Garrity et al. 2010; Kibru et al. 2020), reduced household poverty and improved rural livelihoods (Branca et al. 2020; Clay and Zimmerer 2020), enhanced resilience towards adapting to climate change (Adolph et al. 2020; Aggarwal et al. 2018), and generated capital (including knowledge) to raise future well-being (Andrieu et al. 2020; Wattel and Asseldonk 2018). Thus, environmental concerns can augment welfare in the context of inter-generational and intra-generational equity. Practically, CSA provides a manual for measuring sustainability, preventing sustainability from being a slogan, an empty phrase, or just conveying an expression of emotions.

5 How Can CSA Reduce Women's Vulnerabilities and Improve Priorities and Needs?

Consideration of gender differentiation in implementing CSA options is relevant to achieving equality and equity (Branca et al. 2020; Aggarwal et al. 2018). Understanding the different challenges of women and men in agriculture is essential to build effective household climate-resilience and food systems (Wattel and Asseldonk 2018). The literature suggests that intra-household power inequalities and social norms in SSA underscore why women are disproportionately affected by climate change (Jansson and Hofmockel 2020; Zakaria et al. 2020; Konapala et al. 2020). Moreover, access to resources and ownership of properties are male-dominated which further worsens the climate vulnerabilities of women (Wattel and Asseldonk 2018). Concerning these circumstances, CSA contributes to achieving the environmental, social, and economic priorities of women. Further, the CSA contributes to women's agricultural productivity, lower labour requirements, plus building resilience through additional income, knowledge, and skills towards market value and access. More importantly, strengthening the capacity of women can improve access to productive resources, and the information capital requirement for the optimization of CSA adoption.

6 Conclusion

The study reveals that CSA continues to thrive as a feasible approach in agricultural systems transformation. In SSA especially, CSA is marked as an opportunity to reduce rural poverty, enhance livelihoods while providing knowledge to improve environmental protection. The study found that various practices (derived from indigenous knowledge and new technologies) considered as CSA options are implemented in different SSA countries. Common practices established in the literature and at the farm-level include agroforestry, integrated nutrient management, crop association, soil fertility, and tillage management. Also, residue management, improved varieties, organic fertilization, and drip irrigation were prominent. Even though CSA implementation has made significant progress in SSA, there's a steady growth in up-scaling and out-scaling due to inadequate understanding of the CSA concept and framework, the marginality of agro-ecological regions in SSA, difficulty in mainstreaming CSA into existing policies as well as an inadequate financial investment towards broadening CSA packages. The study recommends that countries strengthen national level institutions and carefully identify opportunities within already existing national policies to support the mainstreaming of CSA. Also, integrated efforts from various economic sectors are needed to evaluate, test and implement practical CSA options with greater potential of achieving sustainable development.

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The Dynamics of Promoting Youth Participation in Smallholder Agriculture for Sustainable Food Security in Lupane District, Zimbabwe

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1 Introduction

A country's population growth usually causes food security associated challenges, resulting from the over tapping of environmental resources to keep up with the demands of a growing population (Haruna et al. 2019). The ever-growing world population has resulted in a lot of debates in local and international conferences particularly on the issues of supply, access and availability of food. Access to land has been seen as a crucial factor in efficient agricultural production which can result in food and poverty reduction in Sub-Saharan Africa (Njeru 2017). Generally, households in rural areas have challenges in securing arable agricultural land. Hence, in most African countries, the importance of land in the food production chain is tied to the socio-cultural, political as well as economic dynamics of the respective countries. Land is an indispensable natural resource that is critical for land-based activities such as the sustenance of livelihoods, employment opportunities, incomes and the provision of food security. Several studies have been done on commercialisation of agriculture for emerging farmers aimed at broadening knowledge on the challenges relating to the change from subsistence farming to commercial farming. However, there is scarcity of scientific information on youth participation in smallholder agriculture. The notion of food security is credited to World Food conference of United Nations Food and Agriculture Organization (UNFAO), held in 1974 (Poppy et al. 2014;

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Haruna et al. 2019). Agriculture has a direct influence on food security. Food security can be described as a state whereby people have access to food that is adequate, safe and nutritious which satisfies their dietary and health needs. Therefore, the urgent agrarian question on how to mainstream youth participation in smallholder agriculture arises. The relationship between youth participation and agriculture has dominated global discourses about the systemic and political challenges confronting small holder agriculture (Losch 2016). Youths have the capacity to contribute to concrete and innovative solutions for sustainable agriculture. However, there are political, economic, and social factors that can affect this goal. In seeking more sustainable agricultural approaches to reduce food insecurity and stimulate agricultural production, resourceful and innovative youths are needed to lead entrepreneurial activities in agriculture (White 2012). When agricultural development is restricted to a few hands, the trickle-down effect brought about by this development is insignificant.

In developing countries, substantial food is produced by the aging smallholders who are unlikely to embrace technology needed to stimulate agricultural production. Even though several studies (Scoones et al. 2019; Inegbedion and Islam 2020) have been conducted on youth participation in agriculture, results have been inconclusive and sometimes contradictory. In addition, the definition of "youth" has been contested as it varies from one government to another. In the global south, youths have been encouraged to participate effectively in agriculture to foster economic development of their agrarian based economies (Nyathi et al. 2018). Hence, youth participation in agriculture can speed up poverty reduction and improve food security. Youths are considered key to socio-economic development, although they can be also classified as an economically vulnerable group. Whilst the current youth cohort is better educated than their parents, an increase in access to education has not expanded employment opportunities in less developed countries. For instance, there is a strong mismatch between newly created jobs and the number of young individuals who enter the labour market annually (DallaValle 2012). The participation in agricultural activities by the youths is a potential game changer in the alleviation of food challenges globally. These challenges are themselves propelled by a host of factors, some of which are linked to environmental degradation. Youths' participation entails asserting their agency in decision-making processes and to be actively involved in the implementation of measures towards meeting specific targets (Haruna et al. 2019). Youths can use their knowledge and skills to raise awareness to the general public on nature conservation through the adoption of socially and environmentally friendly farming methods. Effective participation of youths in agriculture would lead to an increase in food security. Although youths' participation in agriculture is substantial, we hypothesise as follows: H_1: Youths' participation in agriculture largely serves as an alternative solution to unemployment. H_2: Youths' participation in farming is not due to the attractiveness of the sector but it is used as a safety net.

1.1 Study Setting and Methods

The geographical location of the study was Shabula and Shabulanyana villages in Ward 15 in Lupane. Lupane is situated in Matabeleland North, a largely semi-arid and drought prone province of Zimbabwe that is also susceptible to acute water shortages. The district falls in geographical regions IV and V, characterised by low to medium rainfall, averaging 400–600 mm annually (Svubure 2011). Lupane lies at the elevation of 976 m along Victoria Falls Road. According to EMA (2019), the district is not suitable for crop production as the area is dominated by sandy loam soils. Despite the climate related limitations, Lupane is a district that is endowed with other natural resources that include indigenous hard wood timber forests such as (baikiaea plurijuga), Mahogany and Mukwa. Although the district is not well endowed with minerals, it has recently been explored for coal bed methane gas. Figure 1 is a map showing Lupane district.

The study adopted a qualitative case study design. In qualitative inquiry, the intention is not to generalise the findings but rather to get an in-depth understanding of local social dynamics (Lincoln and Guba 2005). In order to understand other people's

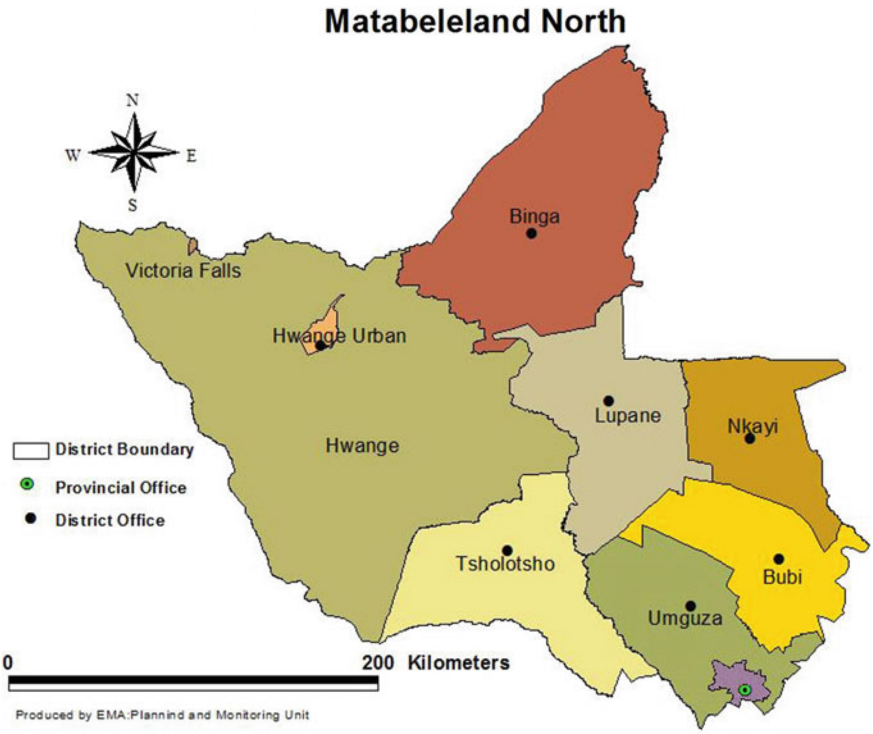

Fig. 1 Lupane district map in Matabeleland North Province

perspectives, the process of questioning is important in qualitative studies. Therefore, a grounded theory approach was used to provide the modes of conceptualisation. Grounded theory has since witnessed a proliferation of many more philosophical perspectives that have influenced a change in methodological development over time (Goulding 2005). Thus, the use of qualitative approach enabled the researchers to discover the origin of the phenomenon, use codes to document individual's experiences and verify theoretical or conceptual structures associated with the phenomenon. The approach also enabled the researchers to understand emotions, feeling and thought processes of participants which may be difficult to gauge through conventional research methods. Hence, coding of data is useful in social research that enables the researcher to conceptualise and integrate data to form a theory. Coding was used as an analytical tool to handle large data and develop alternative meanings of phenomena. We started out with a preliminary visit of the study area in order to have an appreciation of the socio-economic and agro-ecological profile of the selected areas (Chambers 1994). The interview guide was used as a data collection tool which was constructed based on the collection of textual data set referred to as the basic text mining process. The next stage was the data transformation phase where text was filtered in a structured way. In this way words in the text set were analysed in terms of frequency and occurrence. The last stage was the data conversion process, topics and contents within the scope of information extraction were determined. Data was collected between the 7th of January and 15th of February 2020.Using a purposive sampling approach, we conducted fifteen (15) key informant interviews and five (5) focus group discussions (between 8 and 10 participants in each group). With regards to focus group discussions, the five groups were created as follows; one (1) group that comprised of older farmers (men and women), two (2) groups constituted of young farmers (men and women) and two (2) groups that was made of youths (men/boys and women/girls-in and some out of school). The purpose of using different data collection processes was to triangulate information gathered through other techniques. We analysed data using memoing because it looks directly at communication via texts or transcripts, generated and documented ideas through social interaction with data. Memos build a historic audit trail of document ideas that are reflective of interpretive pieces of thought processes that are inherent in providing detailed records of the researchers' feelings, thoughts and intuitive contemplations.

2 Results and Discussion

The outcomes of the study are presented and discussed using themes drawn from the research objectives. Direct anecdotes from the participants are used to substantiate the head of arguments in the findings.

2.1 Factors Affecting Youth Participation in Agriculture

Study participants were asked a question intended at ascertaining the factors that determine youth participation in smallholder agriculture. Our H_1 is youths' participation in agriculture largely serves as an alternative solution to unemployment.

Table 1 presents the qualitative results of the study. The table shows the key components, stage, description and emerging issues that affect youths' participation smallholder agriculture. In order for the youths to participate meaningfully, there is need to look at demographic factors which are determined by youth attitudes, geographic location and land ownership. Other factors include limited access to productive land and unaffordable input costs. Similarly, FAO (2014) opined that trials to access to

Table 1 Factors affecting youth participation in agriculture

Component	Stage	Description	Emerging issues
Demographic	Key informant interviews	*Attitudes influencing youth participation in agriculture are largely geographic and land ownership and they vary extensively*	Youth attitudes Geographic location Land ownership
Communication	Key informant interviews	*Even if there are campaigns for stimulating interest and raise awareness about the positive aspects of agriculture, it is important to do market segmentation in order to target the right segment and ensure that the message reaches the right audience*	Awareness campaigns Stimulate interest Market segment Communication Right audience
Subsistence farming	Focus group discussions	*The youth who come from rural areas are likely to understand agriculture since they have been exposed to subsistence farming as a driver for food security but they may look down upon it since most of the farmers are poor and struggling to grow from subsistence to commercial farming*	Rural areas Subsistence agriculture Food security Commercial farming Lack of finance Poor farming methods
Fundamental asset	Key informant interviews	*Youths are a fundamental asset to a country who constitute an important resource for sustainable agricultural production which is key component in economic development and food security. The growing global populations have given us a challenge for transferring of food production activities to more energetic and younger productive members of society*	Youths are an asset Economic development Sustainable agriculture Food production activities Young and energetic Productive members

(continued)

Table 1 (continued)

Component	Stage	Description	Emerging issues
Access to productive land and high input costs	Focus group discussions	*It is not easy for youths in this community to acquire land for agricultural purposes. In this communal area all land is under the jurisdiction of traditional leadership and you can only access it through them. The challenge is that you can only be given land if you get married. While we appreciate the importance of smallholder agriculture, honestly how do you expect us to participate in it without land. Our main challenge in this community is access to land as youth. Without land you can't even dream of starting an agricultural project. The situation is even complicated for female youths. This community is patriarchal in nature. Priority is given to males with regards to access to and ownership of land. Again, it is difficult It hard to work in a piece of land knowing that the harvest is not yours but for the parents. Even if you want to venture into vegetables instead of these traditional crops, where will you get that small piece*	Access and acquire land; Traditional leadership; Land ownership; Small holder agriculture; Gendered land ownership; Parents own the land
Lack of credit facilities,	Focus group discussions	*Farming needs some capital and most youths that l know here are not credit worthy. They cannot be borrowed money to finance their agricultural activities. Here in Lupane we have the Agri-bank that aims at supporting smallholder farmers. However, one needs some form of collateral to access credit from that bank. How do we make it without land, not even a goat in your name? What l am saying here is that youths might be interested in farming but they are handicapped by inaccessibility of funding of their agricultural activities. I think Agri-bank should consider having a fund specifically meant for youths interested in farming*	No access to capital'; No collateral to access finance; No means to access credit; Consider interests of youths

(continued)

Table 1 (continued)

Component	Stage	Description	Emerging issues
Rural-migration	Key informant interviews	*Young and old aged females were found to be more dominant in rural agriculture due to rural–urban migration by men in search of greener pastures*	Females are dominant in rural areas; Men migrate to urban areas
Family attitudes	Focus group discussions	*As a parent I can't expect my children to be farmers. Show me a farmer who has managed to make it in this community. All the farmers' l know are struggling to survive with some incapacitated to pay fees for their school. I think in this day in age it is important for our children to pursue better livelihood options than farming. We need doctors, lawyers and pilots in this community. That is what we should be focusing on not pushing our kids into poverty. Besides times are changing children also have their dreams and the future ahead of them; they should choose their own careers so as to make us proud parents*	Family expectations; Rural farmers struggle to survive; Children not schooling; Expect better livelihoods options; Need for professionals other than farmers; Farming push kids to poverty; Children should be free to choose their careers
Limited participation Policy planning Agricultural markets	Focus group discussions	*One big problem that I have seen in this community is the market. As youths we are aware of agricultural marketing challenges in this community. For one to make money out of agriculture, they need a viable market of some sort. Without a market to sell your produce you cannot run a sustainable agricultural project. You will get frustrated somehow. To me we are discouraged from venturing in farming because of market uncertainty. Young women in this community face extra restrictions in accessing markets, due to cultural norms and values that limit their freedom of association and movement*	Marketing challenges; Lack of markets; Farming is discouraging; Agro-business viability; Seasonal changes result in uncertainty; Challenges in accessing markets. Restricted movement and freedom of association

(continued)

Table 1 (continued)

Component	Stage	Description	Emerging issues
Access to information Knowledge and skills	Key informant interviews	*Social media can play a cardinal role in promoting youth involvement in agriculture. What needs to be accepted is that youths no longer depend on traditional mediums especially print media to access information. Print media can be inaccessible especially in remote areas. Due to the expansion in connectivity to internet, most youth access information through social media such as Facebook, WhatsApp, internet and other platforms such as twitter*	Access to internet; Use of social media; Shift from traditional marketing tools; Use of social media platforms; Reach the youth demographic
Perennial drought and pestilence Unfavourable climatic conditions	Key informant interviews	*"Over the past years, I have never seen a household having a good harvest in this community. It has been drought after drought. The issue here is that rainfed agriculture has failed everyone. Although farmers have been advised to plant small grains like sorghum and millet, their harvest has remained low because of lack of good seed varieties, lack of manpower, birds and pests. I find it hard to pursue a career in agriculture because it a waste of time, seeds and energy are important in this community."*	Perennial droughts and pestilence affect harvest; Failed rainfed agriculture; Harvests remain low despite good seed varieties; Lack of manpower; Poor harvest due to birds and bests; Career in agriculture is a waste of time
Smallholder agriculture activities	Focus group discussions	*What one needs to understand is that in Shabula and Shabulanyana most of our youths do not own land and are school drop outs with limited access to skills development. That is one of the factors influencing the nature of the activities they are doing in farming. Youths are involved in looking after cattle as herd boys, preparing the fields, fencing, minding birds and in some instances doing harvesting. What we however cannot deny is the importance of their labour in various agricultural activities*	Youths do not own land; Youths are school drop outs; Youths have limited skills; Youths are used as herd boys; Youths are used for minding birds and harvesting; Youths are involved in agricultural activities

Source Developed from the empirical evidence land are some of the most common barriers that deter young people from participating in most agricultural activities. For instance, population growth has reduced land availability to youths thereby cutting them off from long-term occupations in own farm production (Kwenye 2018). Land scarcity and rising land values have affected people's ability to access land and earn a living through farming. The modes of communication are affecting the transmission of messages to youths. Mediums of communication fail to target the right audience and stimulate interest amongst the youths. These factors contribute to 'skills mismatch, where youth in many countries are trained for less marketable vocations' (Jayne et al. 2014). Youths who come from rural areas are likely to support smallholder farming since they know the importance of subsistence farming. However, there were a number of factors that were identified that can affect subsistence farming as a driver of food security. Youths were seen as a fundamental asset to a country who constitute an important resource for sustainable agricultural production. These findings are supported by Afande et al. (2015) and Pindado and Sánchez (2017) who claim that youths are an important asset for the country therefore, food production activities should be transferred to the young, more energetic, and productive members of society. The results show that youths have no access to capital, and they have no means to access credit from financial institutions. Bugaje (2018) posits that more that ninety percent (90%) of smallholders in Nigeria lack collateral which makes it impossible for them to access credit. The majority of financiers are reluctant to support youths due to lack of collateral (Bezu and Holden 2014). The results show that most men migrate to urban areas in search of greener pastures. Agriculture is seen as unattractive for the youths due to family expectations and attitudes. Kusis et al. (2014) argue that youths' negative perception of agriculture is traceable to stereotypes that find currency in media and public discourse. Youths cannot participate meaningfully in agriculture due to limited participation in policy planning and agricultural market development. A study that was conducted by Mitelo (2015) concluded that youth participation in farming positively correlated with being males than females. Education and engagement in wage employment were negatively associated with youth participation in farming. So, technological development presents a paradigm shift to agricultural production. In order to attract youths into agriculture, social media should be used as a tools to reach the youth demographic and acknowledge the youth's shift from traditional mediums especially newspapers that are usually costly. IFAD (2013) claims that, what make matters worse especially in less resourced countries is that 'their education systems do not equip young people for a future in the agriculture sector'. However, due to unfavourable climatic conditions, droughts and pestilence have failed rain-fed agriculture resulting in low harvests despite good seed varieties. Climate change has made growing crops hard in Sub-Saharan Africa (Mabiso and Benfica 2019) which has reduced youth participation in smallholder agriculture (Pindado and Sánchez 2017).

2.2 Livelihood Activities Pursued by Youths Outside Smallholder Agriculture

Findings thus far suggest that variables associated with youth programmes, programme availability, and resources were statistically significant in explaining the factors that affect youth participation in agricultural activities. Our H_2 is that youths' participation in farming is not due to the attractiveness of the sector but it is used as a safety net.

Table 2 shows the results of the study on livelihood activities pursued by youths outside smallholder agriculture. Engagement with participants revealed that migration is one of the sources of livelihood pursued by youth in Lupane. The place is characterised by an aging workforce and persistent decline in the number of young people participating in the agricultural sector (Kwenye 2018). In-depth interviews and focus group discussions and in-depth interviews revealed that most youths have migrated to nearby cities and for some as far as South Africa and Botswana in search of greener pastures. The skewed demographic profiles of household age structure in Lupane is a result of rural youths who tend to be relatively mobile across both national and international borders (Engler and Kretzer 2014). As a result, the intergenerational transfer of agricultural knowledge is threatened, which potentially compromises food security. Youths engage in small scale mining in order to increase incomes and transform lives. Nyathi et al. (2018) revealed that gold panning was sustaining lives of various households in the rural areas since the returns are realised immediately after the activity hence many young people have been absorbed into the mining activity. Over reliance in agriculture was not perceived as an option mainly because climate change has destroyed agricultural prospects resulting in poor yields that are further compounded by infertile soils (Magagula and Tsvakirai 2020). Others have diversified into fishing which requires a fishing licence. Fishing in rural dams has become an important alternative livelihood option for many people (FAO 2013) due to its capacity to contribute to household income and food security (Adelodun 2015). Some of the youths, particularly men are involved in short time jobs while women are engage in cross boarder trading. The results further revealed that youths can be motivated to do smallholder agriculture, however, young farmers need input support and motivation to increase their interest in farming initiatives (Paliwal et al. 2019). For instance, a study that was done by Khapayi and Celliers (2016) concluded that the majority of rural youth in Tanzania and Malawi are engaged in single-occupation farming and youths' participation is decreasing in Tanzania and increasing in Malawi. So, in order for the youths to participate in agriculture, new and efficient farming technologies that are not labour intensive should be made available. Barriers of entry should be removed by giving the youths farming skills. However, young people are unlikely to live in the rural areas and participate in agricultural activities compared to the elderly (Mitelo 2015). Therefore, countries are starting to embark on rural and national transformation by diversifying from agriculture towards manufacturing and more profitable services such as value addition through agri-foods system. So,

Table 2 Livelihood activities pursued by youths outside smallholder agriculture

Component	Stage	Description	Emerging issues
Migration	Key informant interviews	When I finish my form four, I want to go to South Africa because here there is no money. When we look at Mthokoe and Jabue when they come visit in December, they will be having smooth skins and very nice clothes and they even buy us beer in Christmas which shows that they work and get money. The guys are living great life and I envy them so much."	No money at home; Good living for migrants; Perceived better lives
Small scale mining	Focus group discussions	Small scale mining is playing a vital role in creating income and employment prospects for youths in this community. Most of my friends migrate as far as Insiza and Bubi district to search for gold. What you need to understand is that this activity has an advantage over farming in that it does not depend on rainfall. If you are lucky you get substantial monies and transform your life. I have a friend of mine who bought a house in Bulawayo through proceeds from small scale mining. That is very impossible through farming especially here in Lupane where climate change is already biting agricultural prospects and soils are not fertile	Increased incomes from small scale mining'; Small scale mining is better than agriculture; Small scale mining can transform lives; Climate change destroys agricultural prospects; Poor yields due to infertile soils
Fishing	Key informant interviews	Some of us are involved in fishing at the main dam. Fish has a ready market here at Lupane. You can sell to other villagers here in shabula or you go to Lupane centre. Lupane centre has an advantage in that you meet civil servants including university lecturers as part of your customers. The only challenge in dealing with fish is that you need a license for fishing and if you want to secure them from Binga, which is a bit distant from here, you need one as well	Youths have diversified into fishing; Youths sell fish to civil servants; Trading in fish needs a licence; Fish is abundant far in Binga
Menial jobs	Focus group discussions	Youths are involved in small scale mining, trading and migrating in search of jobs in nearby farms and urban areas	Youths are involved in short time jobs; Women prefer cross boarder trading

(continued)

Table 2 (continued)

Component	Stage	Description	Emerging issues
Motivating youths	Key informant interviews	Motivating youths' interest in farming is a not a big deal. Those interested in farming have to access land and also be supported with inputs and loans. I think it is high time that government and NGOs focus on coming up with youth specific farming initiatives. I believe that may assist in motivating youths to venture into farming. Enhancing the adoption of new agricultural technologies that are affordable, efficient and not labour demanding will also assist in attracting youths to venture into farming. Those who are already into farming have challenges in terms of penetrating lucrative markets. There is need for government and other private companies to assist youths on that	Youths can be motivated to do farming; Young farmers need input support; Focus on farming initiatives that interest youths; Avail new efficient farming technologies; Use farming methods that are not labour intensive; Remove barriers to entry; Open new market for youths; Give farming skills assistance to youths

Source Developed from the empirical evidence

gender mainstreaming in agriculture may play a big role in improving the image of the sector and reduce outdated stereotypes such rural, unprofitable and gerontocracy.

3 Conclusion and Recommendations

The study revealed that there is a substantial number of youths who participate in small holder farming. Most of the young people who do not want to participate in farming activities migrate from Lupane thereby altering the household age structure in rural areas. Factors affecting youths' participation in agriculture were found to be lack of capital, few income generation alternatives, no access to productive land, unaffordable input costs, lack of credit facilities, family attitudes and unconducive climatic conditions. Young and old aged females were found to be more dominant in rural agriculture due to rural–urban migration by men in search of greener pastures. The study concludes that smallholder agriculture is the most resilient livelihood option and remains central in addressing youths' unemployment as well as access to and availability of food at household level. The youth cohort in rural Zimbabwe and Africa at large constitute untapped resources, whose potential could be leveraged to substantially contribute to poverty alleviation and economic growth, leading to improved food security. The immersion of youngsters in agricultural activities can remedy poverty and extreme food insecurity in rural areas. There is an urgent need to improve the image of agriculture in order to change the prevalent negative stereotypes about farming. The communal land tenure system needs to be transformed to enable youths interested in agriculture to access land and other agrarian support programmes. The challenges that push rural youths to migrate need to be addressed whilst supporting programmes that strengthen the benefits derived by the youngsters from partaking in agriculture.

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Association of Sustainable Food Security with Climatic and Non-climatic Factors in Gujarat State of India: A District-Wise Panel Data Investigation

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1 Introduction

Climate change has become the biggest challenge for global and national policy-makers and development thinkers, researchers, and scientists to discover effective, conducive methods, adaptation strategies and green technologies to mitigate the climate change's negative consequences on socio-economic and production activities in developed and developing countries (Ye et al. 2013; Kumar and Sharma 2013; Singh and Singh 2019; Farrukh et al. 2020). Increasing maximum and minimum temperature, fluctuation or instability in rainfall patterns, and more occurrence of natural disasters such as floods and drought are examples of climate change (Mahrous 2019). It was seemed that production of food-grain and cash crops has declined due to climate change in India and other agricultural intensive economies (e.g., Kumar et al. 2017; Kumar et al. 2015b; Sharma and Singh 2017; Singh and Issac 2018; Singh and Singh 2019).Furthermore, agricultural sector is caused to increase high possibilities for climate change due to changes in land patterns and extensive use of fertilizer in cultivation which contribute to increase more GHGs emissions in the atmosphere. Agricultural sector is useful to increase socio-economic development and provides food security to the present and growing population in largely agrarian countries (Kumar et al. 2017; Singh and Issac 2018; Singh and Sharma 2018). Hence, the development of agricultural sector must be a prime agenda for national and global policymakers to ensure the food security of population, to create jobs for agricultural workers and farming community, to meet the requirement of raw material for the Agri industries, to provide fodder for livestock, to generate income of farmers, to

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increase rural development, and to reduce poverty and income inequality in developing countries. It would be highly effective for developing economies to achieve the sustainable development goals (SDGs) of united nations by 2030s.

India is an agricultural-intensive economy, and it would be the first populated country shortly (Kumar et al. 2017). Therefore, the agricultural sector will not be in a position to ensure the food security of present and growing population in India in future. Subsequently, the agricultural sector may be in an alarming position due to decreasing quality and quantity of available natural resources, and increasing demand of food-grain products due to rising population. Thus, food security may be adversely affected due to overwhelming population growth, urbanization, industrialization, low productivity of food-grain crops, the rising cost of cultivation, low agricultural R&D investment, abundance application of fertilizer, chemicals and pesticides in cultivation, heavy pressure of population on agricultural sector, and climate change. In India, food security is also negatively impacted due to low economic capability of farmers to cope with climate change, insignificant support from the government for the agricultural sector, ineffective government mechanism and agricultural extension services to mitigate the negative impact of climate change and natural disaster, low trust of farmers in agricultural activities and low application of technological upgradation in farming (Kumar et al. 2015b; Kumar et al. 2017; Arora 2018; Singh and Issac 2018; Singh and Sharma 2018; Talukder et al. 2020).

Furthermore, India has a higher infant mortality rate, larger number of hungry people, lower per capita availability of food-grain and milk production, lower per capita calorie intake availability, and lower per capita energy availability as compared to other agriculturally intensive countries like USA, China and Brazil (Singh and Sharma 2018). Also, India has the largest malnourished children, high-income inequality, poor farm management practices, inefficient government policies towards the agricultural sector, low infrastructural development, and inadequate education and training facilities for farmers across Indian states (Kumar et al. 2017; Arora 2018; Singh and Issac 2018; Singh and Sharma 2018; Singh and Singh 2019). Furthermore, climate change would be a caused to increase more vulnerability for the agricultural sector, ecosystem services and food security in India. Climate change will lead to increase several obstacles to achieve agricultural sustainability in India in future. Subsequently, climate change may be caused to increase more poverty, income inequity, hunger, prices of food-grain products, scarcity of raw materials for Agri industries, and demoralization of government policies and reduction in industrial production in India. Consequently, the livelihood security of farming community, agricultural workers, and ordinary people would be in risk due to climate change and demographical change (i.e., high urbanization, high population growth, over migration of workers from rural area to urban area, overwhelming industrialization and population density) (Singh and Issac 2018; Singh and Singh 2019). Therefore, India needs to implement conducive policies to increase sustainable agricultural development. Sustainable agricultural development is a situation in which agricultural sector is capable to produce enough food for present and growing population, and livestock without destroying the ecosystem services and natural resources (Hensen 1996; Asadi et al. 2013). Agricultural sustainability is also useful to increase food-grain production and income of the farmers as sustaining the quality of ecosystem services and human health (Kareemulla et al. 2017; Jeder et al. 2020). It also nurtures a conducive path for conserving the environmental factors and human well-being (Fallah-Alipour et al. 2018).

Agricultural sustainability has a multidimensional association with socio-economic and other activities. Hence, agricultural sustainability may not be defined by a single activity in a nation or region. Subsequently, assessment of agricultural sustainability is complicated and controversial (Hatai and Sen 2008; Sydorovyeh and Wossink 2008; Fallah-Alipour et al. 2018; Lampridi et al. 2019; Mili and Martínez-Vega 2019; Talukder et al. 2020). For this, numerous studies have developed agricultural sustainability index (*ASI*) or sustainability livelihood security index as the composition of factors that were associated with economic efficiency, social equity and ecological security (Koeijer et al. 2002; Qiu et al. 2007; Sajjad et al. 2014a; Rostami and Mohammadi 2017; Kareemulla et al. 2017; Singh and Issac 2018; Jeder et al. 2020; Valizadeh and Hyati 2020). Existing researchers have also used different indicators to develop agricultural sustainability index at micro to macro level in different countries (Refer to Table 1). Further, agricultural sustainability-related needles can be segregated in three components of food security. Hence, it can be concluded that food security is also associated with environmental, social and economic sustainability (Jeder et al. 2020). Previous studies have also developed food availability index, food accessibility index and food stability index to define food security, and agricultural sustainability index to measure sustainable agricultural development in India and other economies. It can be argued that agricultural sustainability has a significant contribution to increase sustainable food security. Sustainable food security is conducive to produce appropriate food-grain products to meet all people's food requirements and fodder for all livestock in a country (Kumar et al. 2017). However, there are several non-agricultural factors which have positive and significant impact on food security in a nation.

Food security is a situation in which food is available for all people to maintain their active and healthy life (Kumar et al. 2017; Singh et al. 2017). Food security can be observed using per capita calorie intake availability or food consumption expenditure, or per capita dietary energy supply at the individual level (Scanlan 2001; Iram and Butt 2004; Sidhu et al. 2008; Faridi and Wadood 2010). Furthermore, food security varies across individuals, households, regions, and countries (Kumar et al. 2017; Singh and Sharma 2018; Farrukh et al. 2020; Jeder et al. 2020). Thus, appropriate food-grain availability at national level does not ensure the food security at the individual level. Also, it is not feasible to combine food security at macro (national) level to micro (individual) level. Hence, assessment of food security is complicated and controversial at micro to macro level (Kumar et al. 2017; Farrukh et al. 2020). Therefore, previous studies have developed food security index (*FSI*) as integration of food availability index, food accessibility index and food stability index at country, state, regional, household and individual level using primary and secondary data (Demeke et al. 2011; Ismali 2012; Ghabru et al. 2017; Singh and Singh 2019). Most studies have included different indicators of food security to

Table 1 Indicators of agricultural sustainability and food security

Agricultural sustainability index	Food security index
Economic efficiency	*Food availability*
Access to extensive services, agrochemicals use, agronomic diversity, annual precipitation, area under nitrogen-fixing crops, benefit–cost ratio to production, biodiversity, education level, farm's income, farm's size, female work participation rate, fertilizer consumption, food self-sufficiency, food-grain yield, governance and institutional capacities, groundwater depletion, industrial plants, crop insurance, labor and land productivity, machinery application, nitrogen use efficiency, output, and input price, per capita agricultural land, per capita availability of milk and food-grain production, per capita income, per capita value of agricultural production, population growth, poverty, public support and regulation, the ratio of dry land area with the irrigated area, percentage of irrigated area, technology and application, unemployment, the value of agricultural output, water use efficient	Percentage of arable land, agriculture labor per hectare land, caloric availability of food-grain, cereal import dependency ratio, cropping intensity, farm income per hectare land, fertilizer consumption, food-grain production and yield, public spending on agricultural and rural development, percentage of arable land, number of livestock per 1000-person, per capita calorie availability, per capita food expenditure, per capita depth of food-deficit and dietary energy supply, per capita electric power and energy consumption, per capita food production variability, per capita food-grain availability, per capita value of agricultural production, production of pulses, percentage of irrigated area in gross sown area, the ratio of net irrigated area to net sown area, rural connectivity, storage capacity, tractor per hectare land, use of agricultural labor per hectare land
Social equity	*Food accessibility*
Access to infrastructure and services, access to resources and support services, agricultural practices, area under marginal and smallholdings, community managed institutions, contribution to employment and ecosystem services, employed in agriculture, equality in food and income distribution, farmer's education, feeling of independence, female literacy, food self-sufficiency, gender equality, household having electricity, infant mortality rate, literacy rate, maternal survival rate, number of commercial banks, number of primary health centers, physical health of workers, the population having access to safe water, poverty, road connectivity, villages having paved road facility, electrified villages, working condition	Percentage of primary workers, percentage of female population, consumer price index, credit deposit ratio, employment rate, family size, female literacy rate, gender ratio, dependency ratio, income of household, infant mortality rate, labor participation rate, lack of employment opportunity, size of landholding, dependency ratio, share of literate population with per hectare arable land,, per capita gross domestic product, per capita income, poor people on per hectare land, population density, population growth, poverty, railway road length per 1000-person, ratio of agricultural labors to total working population, share of SCs and STs community in total population, ratio of the main worker to the total population, ratio of rural population with the gross sown area, inflation
Ecological security	*Food stability*

(continued)

Table 1 (continued)

Agricultural sustainability index	Food security index
Arable surface area, biodiversity, chemical, and biological soil quality, cropping intensity, depth to the groundwater, fertilizer and pesticides, forest cover, GHGs emission, groundwater availability, groundwater recharge potential, irrigation water, land management, livestock density, meadow grass, net irrigated area, nitrate content of groundwater, non-renewable resources, permanent cropped area, pesticides, population density and growth, poultry, quality of groundwater, urbanization, soil nutrient content, water use efficiency, urbanization	Percentage of households having clean drinking water, percentage of households having primary health care, cereal yield, cropping intensity, employment in agriculture, fertilizer consumption, food-grain area, income inequality, number of fair price shop, per capita CO_2 emission, per capita land under cereal crops, population growth, primary school enrolment/1000 population, share of forest area in geographical area, storage capacity, ratio of gross irrigated area with gross sown area, ratio of literate population to gross sown area, ration shop, urbanization

Source 'D'Souza et al. (1993), Filho et al. (1999), Zhen and Routray (2003), Hatai and Sen (2008), Singh and Hiremath (2010), Rukhsana (2011), Ismali (2012), Hashmi and Shakeel (2012), Shakeel et al. (2012), Sajjad et al. (2014a, 2014b), Kumar et al. (2015a), Latruffe et al. (2016), Kareemulla et al. (2017), Ghabru et al. (2017), Singh et al. (2017), Rostami and Mohammadi (2017), Fallah-Alipour et al. (2018), Singh and Issac (2018), Mili and Martínez-Vega (2019), Lampridi et al. (2019), Mahrous (2019), Farrukh et al. (2020)

define it (Faridi and Wadood 2010; Hashmi and Shakeel 2012; Yu and You 2013; Sajjad et al. 2014b; Singh and Sharma 2018; Jeder et al. 2020; Farrukh et al. 2020). Accordingly, previous studies could use different factors to create *FSI* at macro level. The list of crucial variables which were used by previous researchers to develop food security index and agricultural sustainability index are given in Table 1.

In India, numerous studies have examined the elements of food security at individual, household, village, district, state, and national level using primary and secondary data (Sidhu et al. 2008; Rukhsana 2011; Ismali 2012; Hashmi and Shakeel 2012; Shakeel et al. 2012; Sajjad et al. 2014b; Singh and Singh 2019; Sukhwani et al. 2020). These studies have focused on measuring the relative performance of food security as an integrated index of most useful variables of food security. Limited studies could estimate the *FSI* in a time series to detect fluctuation in food security and its affecting factors at district level in a specific state of India. Moreover, few studies could examine the influence of climate change (i.e., maximum temperature, minimum temperature, rainfall, precipitation, etc.) and geographical location (i.e., latitude and longitude) on food security at the district level in India. As agricultural sustainability-related factors have extensive impact on food security. However, previous studies could not assess the connection between food security and agricultural sustainability-associated variables in India. Furthermore, few studies have estimated the impact of climatic and non-climatic factors on food security using concrete empirical models. Therefore, this study addressed the answer on following research questions:

- *How components of sustainable food security are associated with agricultural sustainability in Gujarat?*

- *Why agricultural sustainability is associated with sustainable food security in Gujarat?*
- *What is the association of sustainable food security with climate change in Gujarat?*
- *What should be climate policy action to mitigate the negative impact of climate change on sustainable food security in Gujarat?*

This study was achieved following objectives:

- *To develops district-wise food security index (FSI) in Gujarat during 2001–2017 using a composite Z-score method.*
- *To examine the effect of climatic and non-climatic factors on on estimated food security index in Gujarat using linear, log-linear and non-linear production function models.*
- *To provide the policy proposal to nurture a conducive path for agricultural sustainability and sustainable food security in Gujarat.*

2 Research Method and Material

2.1 Brief Discussion on Study Area

Gujarat occupied around 19,602,000-hectare geographical area, which counts 5.96% geographical area of India. It's the fastest-growing state in India as it has a significant contribution to the nation's industrial sector. Around 27.61% working population is engaged in the agricultural sector in Gujarat. Thus, agriculture is the main occupation of most people in this state. Gujarat has 5.30 and 7.65% share of livestock and milk production, respectively, in India (Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, GoI 2012). Despite that, per capita calorie intake per day is low in Gujarat (National Sample Survey Organization (NSSO), Department of Statistics (GoI) 2009–2010). Consumption expenditure per person is also lower in Gujarat as compared to national level (NSSO, Department of Statistics (GoI) 2009–2010). Per capita food-grain availability is also lower in Gujarat as compared to other states of India (Directorate of Economics and Statistics, Department of Agriculture and Cooperation (GoI) 2009). Moreover, Gujarat is a destination of 16.63% poor people (Planning Commission (GoI) 2011–12). Gujarat also has a lower food security as compared to Rajasthan, Andhra Pradesh, Haryana, Punjab, Tamil Nadu, and West Bengal Kumar et al. (2017). Thus, 25 districts of Gujarat were considered to estimate the district-wise *FSI* and to assess its influencing factors in this study.

2.2 Data Source

In this study, the food security index (*FSI*) was used as a dependent variable. Climate change and ecological related factors were considered as independent variables which were compiled as district-wise panel data during 2001–2017. Required district-wise data was taken from various sources such as The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Census (GoI), Gujrat Social Development Infrastructure Board Society, General Administrative Department, Government of Gujarat (GoI), Health and Family Welfare Department (GoI), Office of Registrar General and Census Commissioner (India), Agriculture and Cooperation Department (GoI), IMD (GoI). Interpolation and extrapolation techniques were used to complete the time series of most variables (e.g., literacy rate, population size, gender ratio, agricultural labor, urbanization, population density, birth rate and population growth) which do not have the data for in-off and out-off during afore-mentioned time period (Singh et al. 2019, 2020).

2.3 Adopted Technique for Index Estimation

Economic development, social development, livelihood security, entrepreneurship ecosystem, environmental development, food security, nutritional security, agricultural sustainability, global climate risk, agrarian vulnerability, hunger, etc. may not be explained by a specific indicator in a country. Thus, previous studies have created different indexes such as food security index (*FSI*), economic development index, environmental development index, climate vulnerability index, food production index, entrepreneurship ecosystem index, social development index, sustainable development index, global climate risk index, global competitiveness index, global hunger index, crop diversification index, intellectual property awareness index, global peace index, agricultural sustainability index, sustainable livelihood security index, and science and technological development index (*STDI*) in different economies using secondary data in developed and developing countries (Singh and Singh 2019; Mahrous 2019; Jeder et al. 2020; Singh and Ashraf 2020). Existing studies have used principal component analysis, factor components analysis and *composite Z-score* methods to generate indexes described above. Since the *composite Z-score* technique has greater viability than other methods. Therefore, *composite Z-score* technique was used to estimate *FSI* to measure the relative performance food security across district of Gujarat in this study. Here, food security index (*FSI*) is defined as an integration of several factors which were significantly associated with food security. It is a relative index which shows the relative performance of an individual district in food security as compared to other districts. *Composite Z-score* technique is based on *composite-score* and weightage of all arbitrary variables which can be estimated through a statistical approach (Singh and Hiremath 2010; Singh and Singh

2019; Singh et al. 2020). The *composite-score* is useful to convert values of all variables between *0–1*. If a variable was positively associated with food security, then *composite-score* was estimated as (Singh et al. 2020):

$$CS_{id} = \{[X_{id} - Min(X_{id})]/[Max(X_{id}) - Min(X_{id})]\} \tag{1}$$

Here, *CS* is a *composite-score* for *i*th variable, *d* is cross-sectional districts; X_{id}, $Min(X_{id})$, and $Max(X_{id})$ are actual, minimum, and maximum values, respectively for *i*th variables across districts (*d*) in Eq. (1). If a variable was negatively associated with food security, then *composite-score* was estimated as (Singh et al. 2020):

$$CS_{id} = \{[X_{id} - Max(X_{id})]/[Min(X_{id}) - Max(X_{id})]\} \tag{2}$$

The description of variables is given with Eq. (1). The weight of each variable is allotted as:

$$wi = \frac{K}{\sqrt{Var(CS)}} \tag{3}$$

Here, *wi* is the allotted weight for *i*th variable; the sum of all *wi*'s is 1; and *Var*(*CS*) is variation across *composite-scores* of all variables in Eq. (3). The value of *K* is estimated as:

$$K = \frac{1}{\left\{\sum_{i=1}^{n}\left(\frac{1}{\sqrt{Var(CS)}}\right)\right\}} \tag{4}$$

Here, *Var*(*CS*) is variation across *composite-scores* of all variables (*n*) in Eq. (4). Finally, the food security index was considered as a linear sum of all *composite-score* of respective variables (i.e., *n*) which was also multiplied by allotted weights.

3 Empirical Analysis

*3.1 Development of Food Security Index (*FSI*)*

Existing studies have argued that single variable may not be conducive the measure the food security of a nation (Mahrous 2019; Sukhwani et al. 2020). Hence, index-based estimation will be effective to measure the food security at macro level (Ye et al. 2013). In this study *FSI* was considered as a compilation of three components of food security. These components were used as availability of food, accessibility of food, and stability of food (Shakeel et al. 2012; Sajjad et al. 2014b; Kumar et al. 2015a; Kumar et al. 2017; Singh et al. 2017; Singh and Singh 2019; Jeder et al. 2020). Accordingly, in this study, food availability index (*favi*), food accessibility index (*faci*) and food stability index (*fsti*) were developed to observe the food security across districts in Gujarat. Thereupon, the linear sum of these indexes was used to develop food security index (*FSI*). For aforesaid investigation, this study accepts that food security index (*FSI*) can be expressed as function of *favi*, *faci* and *fsti*, and mathematically it can be written as:

$$FSI = f\{(favi, faci, fsti)\} \tag{5}$$

Here, *FSI* is as linear average sum of *favi*, *faci* and *fsti* in Eq. (5). Food availability index (*favi*) includes the factors that are essential to increase food production (Sajjad et al. 2014b). Food availability refers as a situation in which food is available for all community either from domestic food-grain production or imported from the food-grain production surplus areas or providing though food-aid program (Sharma and Singh 2017). Hence, *favi* integrates most related factors which have positive impact on food production (Singh and Singh 2019; Sukhwani et al. 2020). Thus, food production associated variables were considered to create *favi*. Here, *favi* was constructed as:

$$\begin{aligned}(favi)_{dt} = {} & w_1 \times (CS\_pcafgp)_{dt} + w_2 \times (CS\_pcamp)_{dt} + w_3 \times (CS\_pcaep)_{dt} \\ & + w_4 \times (CS\_nlptp)_{dt} + w_5 \times (CS\_pfgagca)_{dt} \\ & + w_6 \times (CS\_fgppal)_{dt} + w_7 \times (CS\_pfaltal)_{dt} \\ & + w_8 \times (CS\_flr)_{dt} + w_9 \times (CS\_phucsw)_{dt} \\ & + w_{10} \times (CS\_alphgca)_{dt}\end{aligned} \tag{6}$$

Here, *favi* is the food availability index; *CS* is the composite-score of the associated variable; $w_1, w_2, \ldots, w_{10}$ are assigned weights for related variables in Eq. (6). A brief explanation of all factors is given in Table 2.

Food accessibility index (*faci*) is associated with economic capacity or purchasing power of the people to buy the required food-grain product from domestic market (Sharma and Singh 2017; Jeder et al. 2020). This component of food security is interlinked with financial assets of people, occupation, income, preferences of food and market mechanism (Singh and Singh 2019; Sukhwani et al. 2020). Therefore, factors which were essential to increase economic capacity of people were used to create *faci* in this study and *faci* was assessed as:

$$\begin{aligned}(faci)_{dt} = {} & w_1 \times (CS\_psalmw)_{dt} + w_2 \times (CS\_tlr)_{dt} \\ & + w_3 \times (CS\_marden)_{dt} + w_4 \times (CS\_nbpmp)_{dt} \\ & + w_5 \times (CS\_rodden)_{dt} + w_6 \times (CS\_pscstptp)_{dt} \\ & + w_7 \times (CS\_infmorrat)_{dt} + w_8 \times (CS\_genrat)_{dt} \\ & + w_9 \times (CS\_urbrat)_{dt} + w_{10} \times (CS\_podden)_{dt}\end{aligned} \tag{7}$$

Table 2 Explanation of food availability index associated factors

Factors/variables	Unit	Symbol	Source of data
Per person availability of food-grain product	kg	*pcafgp*	ICRISAT and census (GoI)
Per person availability of milk production	kg	*pcamp*	
Per capita availability of egg production	Number	*pcaep*	ICRISAT
Number of livestock per 1000-person	Number	*nlptp*	ICRISAT and census (GoI)
The share of cropped area under food-grain crops	%	*pfgagca*	ICRISAT
Food-grain productivity of agricultural labour	kg	*fgppal*	ICRISAT and census
Percentage of female agricultural labour in total agricultural labour	%	*pfaltal*	
Female literacy rate	%	*flr*	Census (GoI)
Percentage household having accessibility of clean source of water	%	*phacsw*	
Agriculture labour per hectare gross cropped area	Number	*alphgca*	ICRISAT and census (GoI)

Source Selection of variables based on existing studies

Here, *faci* is food accessibility index; *CS* is *composite-score*; $w_1, w_2, \ldots, w_{10}$ are assigned weights for related variables in Eq. (7). The explanation of all variables is presented in Table 3.

Food stability index (*fsti*) is associated with those activities which are useful to sustain the equilibrium in supply and demand of food-grain production in domestic market in a region (Singh and Singh 2019; Sukhwani et al. 2020). Cropping intensity, irrigated area, fertilizer consumption, involvement of literate people in farming, food-grain yield, birth rate, accessibility of electricity and safe toilets, and population growth have significant impact on food stability. Therefore, *fsti* was assessed as:

$$\begin{aligned}(fsti)_{dt} =& w_1 \times (CS\_croint)_{dt} + w_2 \times (CS\_rgiagsa)_{dt} + w_3 \times (CS\_rniansa)_{dt} \\ &+ w_4 \times (CS\_fcphagca)_{dt} + w_5 \times (CS\_rtlpgca)_{dt} \\ &+ w_6 \times (CS\_fgy)_{dt} + w_7 \times (CS\_phhae)_{dt} \\ &+ w_8 \times (CS\_phhast)_{dt} + w_9 \times (CS\_birrat)_{dt} \\ &+ w_{10} \times (CS\_popgro)_{dt} \end{aligned} \tag{8}$$

Here, *fsti* is food stability index; *CS* is *composite score*; $w_1, w_2, \ldots, w_{10}$ are assigned weights for related variables in Eq. (8). The clarification of associated variables is given in Table 4.

Table 3 Summary of food accessibility associated factors

Factors/variables	Unit	Symbol	Source of data
Percentage share of agricultural labours in total main workers	%	*psalmw*	Census (GoI)
Literacy rate	%	*tlr*	Census (GoI)
Market density	Per 10,000 km^2	*marden*	ICRISAT
Number of banks per million persons	Number	*nbpmp*	ICRISAT and census (GoI)
Road density	Per 10,000 km^2	*rodden*	ICRISAT
Percentage of SC&ST population in total population	%	*pscstptp*	ICRISAT and census (GoI)
Infant death rate	Number	*infmorrat*	Health and family welfare department (GoG)
Gender ratio	Number	*genrat*	Census (GoI)
Urbanization rate	%	*urbrat*	Census (GoI)
Population density	Person per km^2	*podden*	Census (GoI)

Source Selection of variables based on existing studies

Table 4 Summary of food stability index associated factors

Factors/variables	Unit	Symbol	Source of data
Cropping intensity	%	*croint*	ICRISAT
The share of gross irrigated area in gross cropped area	Ratio	*rgiagsa*	ICRISAT and directorate of agriculture (GoG)
The share of net irrigated area in net sown area	Ratio	*rniansa*	Directorate of agriculture (GoG)
Fertilizer consumption per Ha of GCA	kg/Ha	*fcphagca*	ICRISAT
The ratio of the total literate population with the gross sown area	No/Ha	*rtlpgca*	ICRISAT and census (GoI)
Food-grain yield (total food-grain production/gross food-grain area)	kg/Ha	*fgy*	ICRISAT
Percentage household have the accessibility of electricity	%	*phhae*	Census (GoI)
Percentage household have the accessibility of safe toilets	%	*phhast*	
Birth rate	Number	*birrat*	Health and family welfare department (GoG)
Population growth (in %)	%	*popgro*	Census (GoI

Source Selection of variables based on existing studies

3.2 Adoption of Regression Models for Assessing the Impact of Climatic and Non-climatic Factors on Food Security Index

The main aim of this research was to examine the association of food security with climatic and non-climatic factors. Therefore, *FSI* was used as a dependent or output variable, and the maximum temperature, minimum temperature, rainfall, precipitation, wind speed, ratio of forest area with the gross sown area and technological change were used as independent variables in this study. Demeke et al. (2011), Kumar et al. (2015a), Kumar et al. (2017), Sharma and Singh (2017), Singh et al. (2017), Singh and Issac (2018), Mahrous (2019), Singh et al. (2019), Singh and Singh (2019), Singh et al. (2020), Singh and Ashraf (2020), Jeder et al. (2020) which have also used constructed indexes as output and explanatory variables for various purposes in India and other economies. For the investigation described above, this study accepts that *FSI* is a function of climatic, geographical, and ecological factors. Mathematically, this relationship is specified as:

$$FSI = \{(sfagca), (sppagca), (aaea), (aapre), (aa\max tem), (aa\min tem), (aarf), (aawinspe)\} \tag{9}$$

Here, *FSI* is food security index, *sfagca* is share of forest area in gross cropped area, *sppagca* is share of permanent pasture area in the gross cropped area, *aaea* is annual average actual evapotranspiration, *aapre* is annual average precipitation, *aamaxtem* is maximum temperature, *aamintem* is minimum temperature, *aarf* is rainfall and *aawinspe* is wind speed. As this study was used time series data of *FSI* and other variables, thus, annual average values of aforesaid climatic factors were included in Eq. (9). Linear regression model was used in the following form:

$$(FSI)_{dt} = \beta_0 + \beta_1(ttf)_{dt} + \beta_2(sfagca)_{dt} + \beta_3(sppagca)_{dt} + \beta_4(aaea)_{dt} + \beta_5(aapre)_{dt} + \beta_6(aamaxtem)_{dt} + \beta_7(aamintem)_{dt} + \beta_8(aarf)_{dt} + \beta_9(aawinspe)_{dt} + \mu_{dt} \tag{10}$$

Here, *ttf* is time trend factor which was included to capture the influence of technological change on food security, *d* express the across districts of Gujarat,, *t* is time series, β_0 is constant coefficient; $\beta_1, \ldots, \beta_9$ are regression coefficients or slope of associated climatic and non-climatic factors; μ_{dt} is error term in Eq. (10). The explanation of *FSI* and explanatory variables is given in Table 5.

Table 5 Description of *FSI* and its associated variables

Factors/variables	Unit	Symbol	Source of data
Food security index	Number	*FSI*	Author's estimation
Time trend factor	Number	*ttf*	
Share of forest area in gross cropped area	%	*sfagca*	ICRISAT
Share of permanent pastures area in gross cropped area	%	*sppagca*	
Actual annual average evapotranspiration	mm	*aaea*	
Annual average precipitation	mm	*aapre*	
Annual average maximum temperature	Centigrate	*aamaxtem*	
Annual average minimum temperature	Centigrate	*aamintem*	
Annual actual rainfall	mm	*aarf*	
Annual average wind speed	km/Hour	*aawinspe*	GIS and IMD

3.3 Finalization of Suitable Regression Model

This study was used district-wise panel data during 2001–2017. These districts have high variation in farming-related factors, farmers' socio-economic characteristics, geographical location, availability of ecosystem services, and climatic conditions. Therefore, it is evident that there will be autocorrelation, cross-sectional dependency, and heteroskedasticity in district-wise panel data. Thus, the present study was applied a panel correction error standard estimation model to estimate regression coefficient of explanatory variables with district-wise *FSI* (Kumar et al. 2017; Singh and Issac 2018; Singh et al. 2019, 2020). This model was used to reduce the impact of autocorrelation, cross-sectional dependency, and heteroskedasticity in empirical results.

4 Empirical Results

4.1 Cross Comparison of Districts in Food Security and Its Components

Food Availability: The relative performance of 25 districts of Gujarat in food availability as per the estimated mean value of *favi* during 2001–2017 is given in Fig. 1. The values of *favi* lie between 0.264 and 0.569 across districts. The estimates imply that there exist a high variation in food availability across districts in Gujarat. As *favi* was an integrated component of per capita availability of food-grain production, per capita availability of milk production, per capita availability of egg production, the number of livestock per 1000 person, percentage share of the food-grain area

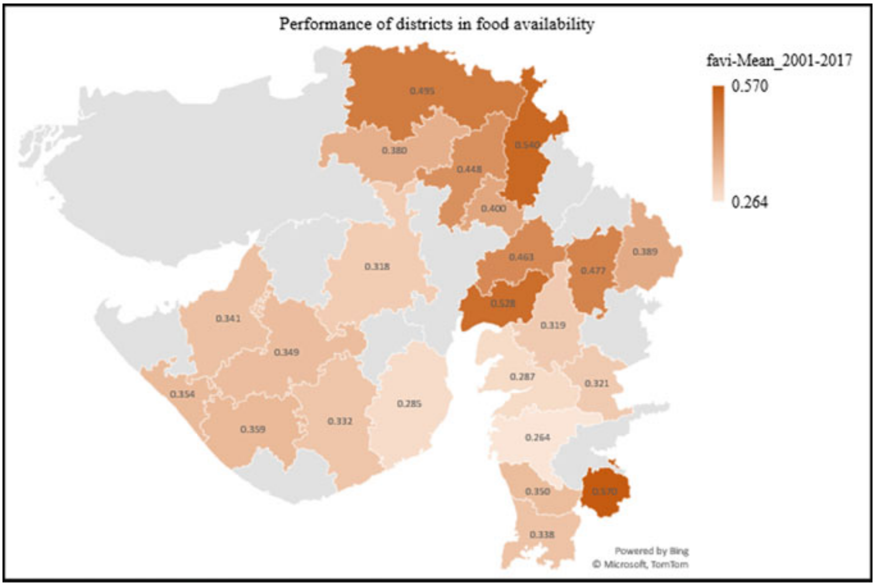

Fig. 1 Cross comparison of districts in food availability. *Source* Author's estimation

in the gross cropped area, food-grain productivity of agricultural labor, percentage of female agrarian labor in total agricultural labor, female literacy rate, percentage household having the accessibility of clean source of water, and agricultural labor per hectare gross cropped area. These variables (except female literacy rate and percentage of the household having the accessibility of clean water source) were positively correlated with *favi*. Therefore, these variables were found most crucial determinants for food availability. The estimates also suggested that government should focus their policy to increase the performance of farming related activities to increase the food availability component of food security. As per the estimated values of *favi*, Dangs, Anand, and Sabarkantha have the best performance in food availability among the 25 districts of Gujarat. Surat, Narmada, Bharuch, and Bhavnagar have the most inferior account in food availability. Thus, these districts need to focus on the variables mentioned above to increase their position in food availability.

Food Accessibility: The comparative status of cross districts in food accessibility based on estimated mean value of *faci* during 2001–2017 is given in Fig. 2. The *faci* values lies between 0.399 and 0.721 across districts. The estimates infer that undertaken districts have high diversity in food accessibility. In this study, *faci* was considered as a composite index of percentage share of agricultural labors in total primary workers, total literacy rate, number of banks per million persons, market and road density, percentage of SC&ST population in total population, infant mortality rate, gender ratio, urbanization rate, and population density. The percentage share of agricultural labors in total main workers, literacy rate, number of banks per million persons, market and road density, and the gender ratio were positively associated

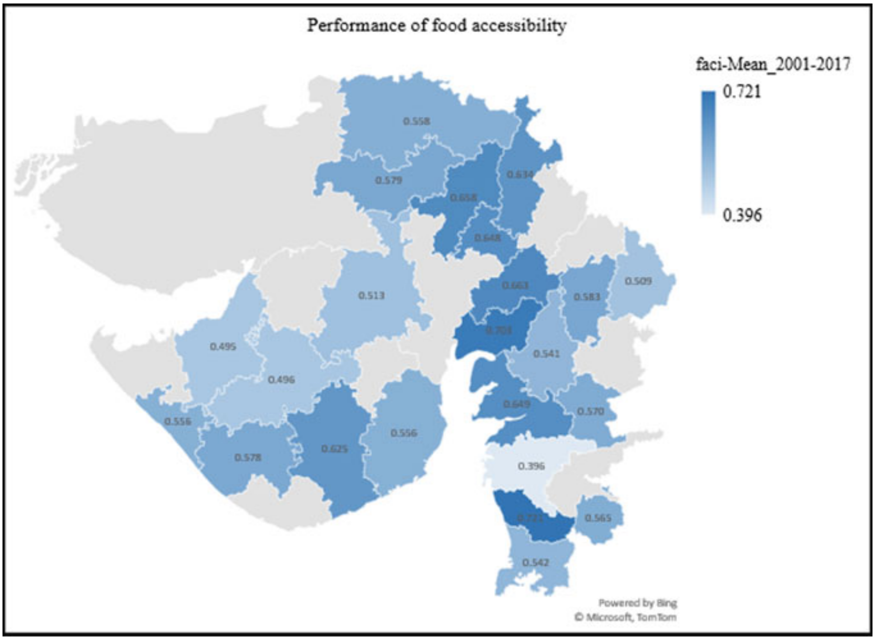

Fig. 2 Cross comparison of districts in food accessibility. *Source* Author's estimation

with food accessibility. Thus, some districts such as Anand, Amreli, Bharuch, Gandhinagar, Kheda, Mahesana, Navsari, and Sabarkantha have the best position in food accessibility due to their effective performance in the mentioned variables. Surat, Rajkot, Kachha and Jamnagar have a relatively low place in food accessibility.

Food Stability: The relative performance of food stability based on mean values of *fsti* across districts during 2001–2017 is given in Fig. 3. The *fsti* was a combination of cropping intensity, the share of gross irrigated area in the gross cropped area, the share of net irrigated area in the net sown area, application of fertilizer per hectare land, the ratio of the total literate population with the gross sown area, food-grain yield, household have the accessibility of electricity and safe toilets, birth rate and population growth in this study. These variables (except birth rate and population growth) were positively correlated with *fsti*. Thus, these variables were seemed most useful determinants to increase food stability. Gandhinagar has a more superior position in the variables mentioned above; therefore, this district could maintain better position in food stability among the 25 districts of Gujarat. It was also observed that all districts have high diversity in food stability due to significant variation in its associated variables. Dangs was seemed most vulnerable district in food stability due to its lowest position in most factors which were essential to increase food stability component of food security. Birth rate and population growth were negatively associated with food stability. Thus, it is suggested that policymakers should think to control the birth rate and population growth to increase food stability in Gujarat.

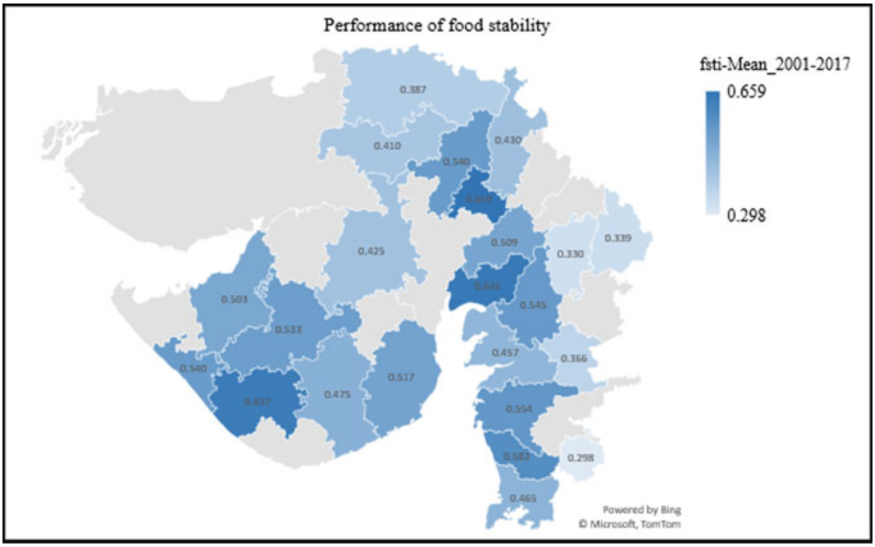

Fig. 3 Performance of districts as per the estimated values of food stability index. *Source* Author's estimation

Food Security: The cross comparison of districts in food security as per the estimated mean values of *FSI* during 2001–2017 is given in Fig. 4. As *FSI* was a combination of *favi*, *faci* and *fsti*. Hence, few districts have the best performance in food security due to their better position in food availability, food accessibility and food stability. The comparative status of undertaken districts as per the estimated mean values of *favi*, *faci* and *fsti* during 2001–2017 is given in Fig. 5. Furthermore, the correlation coefficient of *FSI* with *fvai*, *faci* and *fsti* were also seemed positive and statistically significant (Refer to Table 6). Thus, the estimates show that food security will be improved as increase in food availability, accessibility, and stability. It also infers that these three components were appeared the crucial driver to increase agricultural sustainability and food security. Anand district has shown the best food security position due to its best performance in three components of food security as compared to other districts of Gujarat (Refer to Figs. 4 and 5). Gandhinagar, Junagadh, Kheda, Mahesana, Navsari, and Sabarkantha have the *FSI* values of more than 0.5. Therefore, these districts also have better position in food security. Dahod, Kachchh, Surat, and Surendranagar have a poor position in food security as these districts have lower position in all components of food security.

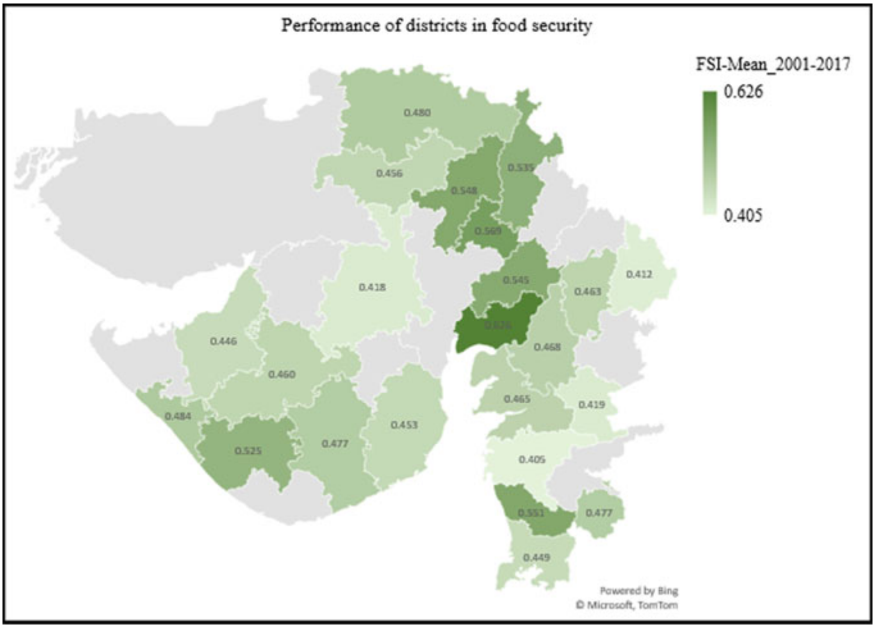

Fig. 4 Cross comparison of districts in food security. *Source* Author's estimation

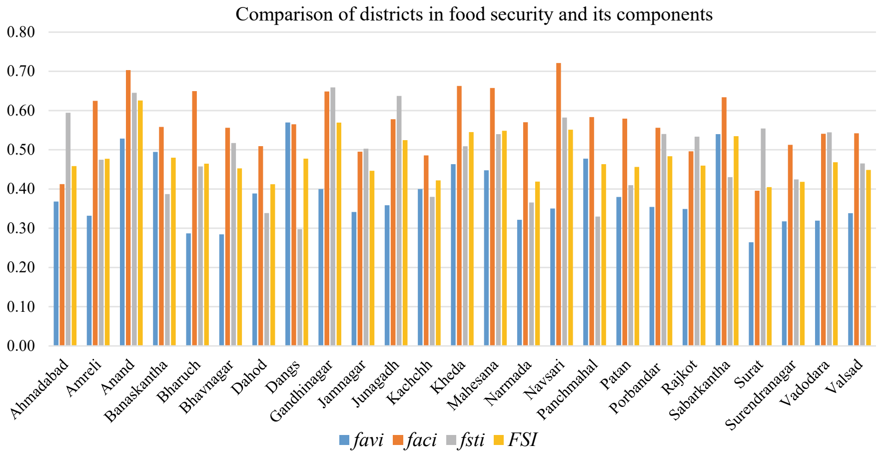

Fig. 5 Performance of districts as per the estimated values of food security index and its associated indexes. *Source* Author's estimation

Table 6 The correlation coefficient of food security index with its associated indexes

Variables	*FSI*	*favi*	*faci*	*fsti*
FSI	1	0.547**	0.731**	0.577**
favi	0.547**	1	0.289**	−0.191**
faci	0.731**	0.289**	1	0.136**
fsti	0.577**	−0.191**	0.136**	1

Source Author's estimation. **Correlation coefficient is significant at the 0.01 level. *Correlation coefficient is significant at the 0.05 level

4.2 Regression Coefficients of FSI with Climatic and Non-climatic Factors

The regression coefficients of FSI with climatic and ecological factors is expressed in Table 7. As a linear regression model produces the lower values of Akaike information criterion (*AIC*) and Bayesian information criterion (*BIC*) as compared to the log-linear and non-linear regression models. Hence, linear regression model produces consistent results. Accordingly, the regression coefficients of *FSI* with explanatory variables based on this model were used to provide the statistical interpretation in this study. Time trend factors have a positive impact on *FSI*. Hence, the estimate suggested that more applications of technologies in farming will be useful to increase agricultural production and food security. Also, technological advancement would be useful to increase agricultural sustainability. The regression coefficients of maximum temperature, rainfall and wind speed with food security index was seemed negative and statistically significant. The estimates imply that food security was adversely affected due to increase in maximum temperature, rainfall, and wind speed in Gujarat. Further, the estimates also imply that food security may be decreased as an increase in aforesaid climatic factors. Share of forest area in gross cropped area and share of permanent pastureland in the geographical location have a negative impact on *FSI*. Thus, food security may decrease as an increase in the forest area. It may be happened due to that arable land may decrease as an increase in the forest area. Accordingly, food production and food security may be declined. Furthermore, most climatic and ecological factors have a non-linear association with *FSI*.

5 Results and Discussion

This study's descriptive results indicate that *favi* was positively associated with per capita availability of food-grain, milk, egg, livestock production, area under food-grain crops, agricultural labor productivity, female agricultural worker, accessibility of clean source of water, and female literacy. The estimates were consistent with previous studies such as Rukhsana (2011), Ismali (2012), Shakeel et al. (2012), have

Table 7 The regression coefficients of climatic and ecological factors with FSI

Statistical tests	Linear regression model		Log-linear regression model		Non-linear regression model	
No. of Observation	425		391		425	
Mean of variance inflation factor (VIF)	2.72		2.97		918.76	
R^2	0.2419		0.2839		0.301	
Wald Chi2(15)	1187.97		1014.23		1345.79	
Prob > Chi2	0.000		0.000		0.000	
AIC	−1304.079		−1312.09		−1322.58	
BIC	−1263.558		−1272.4		−1249.64	
fsi	*Reg. Coef*	P > |z|	*Reg. Coef*	P > |z|	*Reg. Coef*	P > |z|
year	0.0005	0.293	0.00088	0.101	0.0005	0.392
sfagca	−0.00109	0.000	−0.02540	0.000	−0.0028	0.000
(*sfagca*)^2	–	–	–	–	0.0000	0.000
sppagca	−0.00252	0.005	0.00422	0.405	0.0001	0.941
(*sppagca*)^2	–	–	–	–	−0.0002	0.150
aaea	0.00104	0.000	0.00420	0.762	−0.0011	0.315
(*aaea*)^2	–	–	–	–	0.0000	0.049
aapre	−0.00006	0.312	0.00295	0.757	−0.0005	0.037
(*aapre*)2	–	–	–	–	0.0000	0.028
aamaxtem	−0.00863	0.001	−0.44837	0.000	−0.1441	0.053
(*aamaxtem*)^2	–	–	–	–	0.0020	0.063
aamintem	0.00285	0.324	0.05253	0.483	−0.3556	0.002
(*aamintem*)2	–	–	–	–	0.0084	0.002
aarf	−0.00001	0.108	−0.00045	0.955	0.0000	0.739
(*aarf*)2	–	–	–	–	0.0000	0.928
aawinspe	−0.00482	0.354	−0.04956	0.005	−0.0784	0.025
(*aawinspe*)^2	–	–	–	–	0.0101	0.032
Constant Coefficient	−0.35637	0.719	0.20276	0.846	5.9982	0.004

Source Author's estimation

reported that per capita availability of milk, egg and livestock production and food-grain area are the crucial drivers to increase food availability. A literate person has a more understanding of government policies, better choice of food, earning sources and ability to search better jobs. Thus, literate person greatly contributes to increase food security. Female agricultural labors, female literacy, and their participation in farming play a positive role to increase food availability (Hatai and Sen 2008; Rukhsana 2011; Ismali 2012). Water is a prime source to meet the nutritional content in the human body and it is a crucial input for farming. Therefore, accessibility to clean water sources showed as positive impact on food availability (Singh and Issac 2018).

Share of agricultural labors in total primary workers, literacy rate, number of banks per million persons, market and road density were positively correlated with *faci*. More involvement of agricultural laborers in farming may be useful to increase productivity and their economic capacity. Thus, creation of more jobs in agricultural sector would be helpful to increase the accessibility power of agricultural workers to acquire food as per their requirement (Rukhsana 2011; Ismali 2012). Subsequently, food security will be improved as increase in economic capacity of agricultural workers. Financial support for farmers from the banking sector is useful for increasing their economic capacity to apply various inputs in farming. Accordingly, appropriate banking facilities have a crucial contribution in expanding the food accessibility of farmers. Infrastructural development such as road and market are also effective to increase the accessibility of people. Hashmi and Shakeel (2012), Kumar et al. (2017) have also noticed the favorable implication of road length and market density on food accessibility in India. Infant mortality rate, urbanization rate and population density have a negative influence on food accessibility. Inadequate health facilities may be caused to increase infant mortality rate (Tripathi 2017), and it may be responsible for increasing the additional financial burden on people. Accordingly, food accessibility of people may be declined due to increase in infant mortality rate. Arable area and food production may decrease due to the rise in extensive urbanization and population growth, and over burden of population on ecosystem services (Singh et al. 2017). Hence, it is expected that food accessibility will be negatively impacted due to an increase in urbanization and population density.

Cropping intensity, the ratio of the gross irrigated area with the gross cropped area, fertilizer consumption, participation of the literate population in cultivation, food-grain yield, accessibility of electricity, and safe toilets were positively correlated with *fsti*. Previous studies like Rukhsana (2011), Hashmi and Shakeel (2012), Shakeel et al. (2012), Kumar et al. (2017) have also observed the positive impact of the variables mentioned above on food stability. Cropping intensity, irrigated area, and suggested fertilizer application in farming are useful to increase production and yield of food-grain crops. Thus, these variables were seemed conducive to increase food stability. Furthermore, it was also found that food-grain output and yield, food-grain cropped area, agricultural labors' share in primary workers, cropping intensity, the ratio of the gross irrigated area with the gross cropped area, and fertilizer consumption have a significant contribution to increase sustainable food security. Therefore, it is suggested that agricultural production-associated activities play a vital role to ensure sustainable food security. Previous studies such as Yu and You (2013), Kumar et al. (2017) claimed that larger agrarian economies should increase food-grain production to ensure sustainable food security. *FSI* was positively correlated with *favi*, *faci,* and *fsti.* Hence, it was found that all components have a significant role to ensure the food security in Gujarat. The estimates were similar to previous studies such as Sharma and Singh (2017), Kumar et al. (2017), Singh and Singh (2019) which have reported positively association of food security with its main components in India.

Share of forest area and permanent pasture area in gross cropped area, annual average maximum temperature, annual actual rainfall, average yearly precipitation, and average yearly wind speed have negative influence on *FSI*. Thus, the estimates imply that food security may decrease due to increase in variability or change in climatic factors. Several studies have found that production, yield and cropped area of food-grain crops would decline due to increase in climatic factors (i.e., maximum temperature, rainfall pattern and precipitation) in Indian states including Gujarat (Kumar et al. 2015b; Singh et al. 2016; Kumar et al. 2017; Sharma and Singh 2017; Singh and Issac 2018). In this study, *FSI* was an integration of mostly agricultural related factors such as production of food-grain, milk, egg, food-grain area, cropping intensity, irrigated area and food-grain yield. Therefore, it is obvious that *FSI* was also negatively impacted due to change in maximum temperature, rainfall variability, wind speed and precipation. Furthermore, previous studies such as Kumar et al. (2017) Singh and Issac (2018) have also perceived an adverse effect of maximum temperature, rainfall pattern, and precipitation on India's food security. Cultivated land may be declined due to an increase in the forest and permanent pasture areas. Thus, production of food-grain crops and food security may decrease due to increase in forest area and permanent pasture area.

6 Concluding Remark and Policy Implications

The descriptive results of this study reveal that food security was positively associated with availability of food, accessibility of food, and stability of food. Thus, there needs to improve all associated components of food security to increase agricultural sustainability and sustainable food security in Gujarat. Sustainable food security associated variables would be useful to increase agricultural sustainability and vice-versa. Components of sustainable food security were positively associated with agricultural sustainability. Furthermore, 25 districts of Gujarat have high diversity food security due to high variation in its associated variables. Accordingly, there exists a significant variation in food security and agricultural sustainability across districts of Gujarat. The estimated values of *favi*, *faci* and *fsti* attract the attention of policymakers to adopt policy initiatives to increase food security at the district level in Gujarat. For instance, policymakers require implementing conducive policies to control infant mortality rate, birth rate, urbanization, population density, and population growth to maintain sustainable food security and agricultural sustainability in Gujarat. Furthermore, more irrigation facilities, accessibility of clean water sources and electricity, advanced technologies, green technologies, credit facilities for farmers, and appropriate market accessibility for the farmers would be helpful to increase sustainable food security and agricultural sustainability in Gujarat. The government should increase the public investment for agricultural research and development to discover more green technology, seeds and environmentally favorable inputs for agricultural sector to cope with climate change. Therefore, agricultural sustainability will be useful to maintain sustainable food security and vice-versa.

The empirical results also indicate that precipitation, maximum temperature, rainfall, and wind speed have negative impact on *FSI*. Therefore, food security and agricultural sustainability were adversely affected due to increase in climate change in Gujarat. Hence, there needs to search active mitigation and farmer's adaptation techniques which can mitigate the negative impact of climate change in agricultural sector. The association of *FSI* with evapotranspiration and time trend factors were appeared optimistic. Thus, evapotranspiration and technological advancement may be supportive for sustainable food security and agricultural sustainability in Gujarat. As agriculture products are the fruit of land, air and water. It is proposed to sustain ecosystem services of land, water and forestry to increase sustainable food security and agricultural sustainability in Gujarat. Farmers should adopt rainwater-harvesting system and rainwater storage facility to meet the irrigation requirement of cultivation in future. The government should provide special benefits for weaker section of the society and small farmers to ensure their food security.

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Integrating Lean Concepts in Smallholder Farming to Catalyze Sustainable Agriculture for Food Security in Trinidad, WI

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1 Introduction

There is great emphasis on increased production with a limited focus on sustainability (Rockström et al. 2017) while ignoring the complementary factor of reducing losses and wastage in food production as a strategy to achieve sustainable food and nutrition security (Hodges et al. 2011). This chapter critically examines methods to integrate lean management in smallholder agriculture as a catalyst to achieve sustainable agriculture, food, and nutrition security in Trinidad, WI.

Food losses and wastage exist along the supply chain during production, post-harvest operations, and processing (Parfitt et al. 2010). According to Gustavsson et al. (2011), most of these losses occur in developing countries at the early stages of production and harvesting due to inadequate harvesting technologies, timely transportation, and improper storage (Papargyropoulou et al. 2014). Post-harvest losses in smallholder farming are due to inadequate market facilities and access to cold storage facilities (Hodges et al. 2011; Tefera 2012). According to Dobermann and Nelson (2013, p. 2), the food systems and agricultural production must be 'less wasteful' by becoming more productive, resource-efficient, and resilient.

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Dora et al. (2015) argue that there are insufficient literature and understanding of lean management in agriculture and farming so far, and therefore its introduction is necessary given the magnitude of waste and losses generated at different levels of production. However, the application of lean in the agricultural industry is complex due to the perishability of most food products, complexity along the supply chain and, a preference of consumers (Dora et al. 2016). The perishable agricultural products require effort to reduce lead times (Mahalik and Nambiar 2010) to avoid wastage of unmarketable products due to their early expiry shelf life (Pauls-Worm et al. 2014).

Several studies indicate that lean practices can help the agricultural sector become more productive, such as Colgan et al. (2013) case study of 'Northumbrian Farm' and Taylor (2006) lean in the UK's pork sector. According to Krafcik (1988), the lean production concept desires to achieve waste reduction, maximize efficiency, and increase economic value due to productivity, quality, and flexibility as the primary performance indicators. The intention is to reduce wastage in human efforts, inventories, manufacturing space, and time in responding to customers' demand for quality products (Womack et al. 1990).

Lean management helps organizations maintain a standardized process and continuously improve the processes to effectively reduce all types of waste (Cudney and Elrod 2011). However, it faces more implementation issues such as culture change, lack of participants involvement and empowerment (Bhatia and Drew 2006). Therefore, leadership in lean organizations must ensure all employees' full engagement, and involvement in daily improvement activities (Dombrowski and Mielke 2014). The failure of lean initiatives often occurs when leaders cannot effectively demonstrate the need for systemic change (Al-Balushi et al. 2014) or manage by a process instead of its outcome (Toussaint 2015). Therefore, it requires a cultural change in empowering and encouraging employees to adopt lean thinking to improve the system (Drotz and Poksinska 2014).

According to Browning and Sanders (2012), applying lean principles requires a thoughtful process to avoid the methods from becoming emaciated and uncompetitive. Implementing lean should relate to the current environment (Corbett 2007) and consider the methods and reason for implementation (Handfield and Melnyk 1998). The constant focus to improve and remove waste can result in an obsession with significant work-related stress (Nayab 2011). Therefore, it is necessary to use lean concepts scientifically (Spear and Bowen 1999 emphasizing training and learning as central components in the processes (Holweg 2007).

Ohno (1988) identified seven categories of waste, including overproduction, wastage in processing, transportation, non-working and waiting time, high or low inventory, unnecessary movement of people, correcting waste, and defective products, Fig. 1. Womack and Jones (2003) included an eight-type, such as designing products and services which the customer does not require or meet the customer's requirements.

This chapter presents smallholder farming trends in Trinidad towards attaining sustainable agriculture to achieve food and nutrition security. It examines the Government's policy in state land distribution for smallholder farmers, the national agencies of Agricultural Marketing and Development Corporation (NAMDEVCO) and

Fig. 1 7 Forms of waste (Ohno 1988) Google: free access

the Development Bank (ADB). The paper also presents Ro-Crops Agrotec, an agroecology 1.5-ha family farm in Central Trinidad, as a case study and change agent.

2 Methodology

The research consisted of a literature review based on a mixed-method (qualitative and quantitative) (Bettany-Saltikov 2012) from credible sources in the English language on Edinburgh Napier University online library and other sites such as Web of Science, Scopus, AgEcon, and Google scholar databases. These extensive reviews aim to minimise researcher bias (Petticrew and Roberts 2006). It examined the trends of smallholder farming in Trinidad and reviewed research papers on sustainable agriculture by the Ministry of Agriculture and the Government's land policy documents. It also investigated NAMDEVCO's Farm Certification protocols with its Chief Executive Officer and Facilities Managers on its Good Agricultural Practices (GAP). The research examined postharvest management at its Wholesale markets and Packing House facilities regarding implementing lean management concepts. NAMDEVCO's CEO approved undertaking the case study and utilise the information gathered only for the research. It also researched the financial support which the national Agricultural Development Bank (ADB) provides to the agricultural sector.

The researchers focused on a retrospective analysis of the development of Ro-Crops as a model farm. It used a single-case descriptive study with chronologic key-turning points in the farm's development identified through document analysis (content and theme) procedures (Bowen 2009; O'Leary 2014). The research consisted of a deviant purposive case sampling method (Kuzel 1999) since the researchers they actively participated in the farm development or were aware of its history and repute through publication, specifically related to addressing the challenges of ameliorating and managing the farm's heavy clay, low fertility-acid soils.

The process also directly integrated participant's data into the analysis as themed-narratives and commentaries (Bowen 2009) from the farmer, the lead author of this study. These commentaries became valuable as supplementary or complementary, mainly when the details of farm records seemed confidential or data not recorded systematically for metric analysis. The farmer's narratives helped gain insight into strategic business management processes and decisions, which could not necessarily be captured or traced using metric data. The researchers used the farmer's field observations to meter interpretation of metric data (on-farm trials) for congruency using practices described by Robinson et al. (2007). They also used the document and archival data to construct and validate the farm's history, achievements, processes, financial health, and relationships with collaborating partners and communities.

3 Literature Review

3.1 A Global Perspective

According to the UN (2019), the world population expects to reach approximately 9.6 billion by 2050 (UN 2019) with the prospect of attaining a staggering 11 billion during this century (Gerland et al. 2014). To meet this challenge, it requires a 60 and 110% (70%) increase in food production (Dobermann and Nelson 2013; Pardey et al. 2014; UN 2013) to be grown in adverse conditions due to climate change (Hanjra et al. 2013; Wheeler and von Braun 2013). These challenges constitute a social-ecological framework for intensifying sustainable agricultural development worldwide (Jackson et al. 2012). This immediate solution of increasing agricultural production competes for scarce natural resources of land, water, protected areas, and forest as requirements for a healthy environment and biodiversity (Godfray et al. 2010; Phalan et al. 2011).

While over 870 million chronically undernourished people exist, almost one-third of global consumer food is wasted or lost along the supply chain, estimated at above 1.3 billion tons (Kojima and Ishikawa 2013). A large proportion of smallholder farmers constitute the estimated 2 billion people who are micronutrient deficient and rely on agriculture and food production for their livelihood and sustenance (FAO 2019). The "losses" that occur at the retail and consumer stages are due to wastage consisting of discarded raw or cooked food (Gustavsson et al. 2011; Miller and Welch 2013; Parfitt et al. 2010). These post-harvest losses (PHL) contribute to food insecurity due to environmental degradation, waste of natural and non-renewable resources, including human labour, fertilizer, and energy in production, storage, and transportation (Bai and Dent 2006).

Perishable products such as vegetables and fruits suffer more loss and wastage than staple due to improper post-harvest handling (Yu and Nagurney 2013). This loss and wastage negatively affect food availability to the poor (Murthy et al. 2009). However, a 50% in waste reduction along the post-harvest supply chain can potentially provide the nutritional requirements of approximately 63 million undernourished people worldwide (Munesue et al. 2015).

4 Smallholders Farmers

Several sources indicated that approximately 500 million smallholder farms worldwide cultivate on under 2 ha size farm (Hazell et al. 2010; HLPE 2013). Smallholder farms in many regions occupy lands without adequate tenure held under customary or informal agreements, mostly in risk-prone environments with poor or marginal soils, which further reduces their resilience to climate change and sustainable production (Bautista-Solís et al. 2014; Locatelli 2016). Over two billion rural people occupy these farms (FAO 2019), which comprise 84% of all farms with a 30% global food production (Lowder et al. 2019).

Moreover, these farmers constitute approximately 75% of the underprivileged, undernourished and hungry, people (Wiggins and Keats 2013). They generally avoid monocultures and have benefited from their ability to cultivate and market crops with a high degree of biodiversity in building their resilience to an economic crisis and potentially a mainstay for implementing Sustainable Development Goal 2 (Terlau et al. 2018). Smallholder farmers have a significant role in developing sustainable future food systems (Hong 2015; SDSN 2013) because industrial agriculture has a high dependence on external farm inputs, which increases their vulnerability to increasing incidences of pests, diseases, and changing climatic conditions (Altieri et al. 2015).

Despite smallholder farmers contribution to food security, they are most vulnerable to climatic impacts, which result in significant yield gaps (Lindoso et al. 2012; Tittonell and Giller 2013). Additionally, they have limited adaptive capacity to climate change due to inadequate technical knowledge, experience, low income, small farm size, and access to technical assistance and marketing facilities (Tran and Brown 2019). Further, the general marginalization characteristic of smallholder farmers results from a lack of access to resources, capital, assets, and technical information (Murphy 2010). From a globalisation perspective, smallholders appear inadequate to cope with production challenges due to inadequate investment capacity, economies of scale, and a lack of technical knowledge, which will likely contribute to their decline over time (Collier 2008).

4.1 Challenges to Implement Lean

There are several constraints and challenges which smallholder farmers encounter in achieving sustainable agricultural development, including land tenure and succession, accessing capital, production challenges, postharvest management, social and environmental constraints.

4.1.1 Land Tenure and Succession

Succession planning provides an essential mechanism to achieve production at a sufficient and sustainable level to attain food security (Hicks et al. 2012). There exists a lack of comprehensive land policy for many farmers, and primarily women farmers have no rights to their farm (Dioula et al. 2013). Secured land rights ensuring permanent farmland retention provides an incentive and encouragement for farmers' investment in sustainable development to increase their output and long-term benefits (Ali et al. 2012). The capability to access investment capital enables farmers to build resilience and become sustainable (Thulstrup 2015). Additionally, land ownership facilitates succession planning, which stimulate on-farm and business investment by the current farmers (Cassidy et al. 2019). According to Cassidy et al. (2019), succession also facilitates the transfer of traditional knowledge and skills to sustain changes in styles and practices of farming.

Data shows up to a 10% increase in farm diversification by transferring land from generation to generation (Barbieri et al. 2008). According to Mann et al. (2013), where a successor is appointed, it provides an incentive for investment in the farm and its activities by the older generation while it motivates the younger farmer (successor) to increase the farm's outputs through involvement in other farming activities and to increase the size of their holding.

On the other hand, most farmers without secured land rights focus more on achieving short-term benefits from their investment (Akram et al. 2019). As a result, their investment is more in agricultural supplements to help increase productivity which gradually diminishes the soil fertility and sustainability (Ali et al. 2012; Kumari and Nakano 2015). Unsecured land tenure or leases further deter farmers' investment in sustainable soil conservation technologies due to the uncertain expectation of a healthy future return on investment (Gavian and Ehui 2002).

When these farms become unviable, many farmers seek other type of employment or migrate to the city or abroad (de Schutter 2011), which negatively impacts achieving self-sufficiency and food sovereignty (IFAD and UNEP 2013). With an aging population of farmers not having a successor, there are questions on the future of smallholder farming (Cassidy et al. 2019). A further area of concern is youth's apparent aversion to farming as a future option (Cuervo and Wyn 2012; Proctor and Lucchesi 2012; White 2012) and parents actively discouraging their children from farming careers (Ball and Wiley 2005).

4.1.2 Education and Sustainability

Education is projected as the "greatest resource" to achieve a just and ecological society (Schumacher 1973, p. 64) and as an essential tool for sustainability (Hopkins and McKeown 2002). In many countries, the basic education level is too low, hindering national plans for sustainable development (Hopkins and McKeown 2002). A 'meta-entry' on education by Roser and Ortiz-Ospina (2016) states that while there is a global improvement in education, many countries have youths with literacy rates below 50%, especially in sub-Saharan Africa.

However, a country's shifting to information or knowledge-based economy subtly requires combining higher education, research, and life-long learning (UNESCO-ACEID 1997). Agriculture requires a minimum education level of four to six years as the threshold for increasing productivity (Philips 1994). An additional year of agricultural studies and training can significantly improve productivity (Djomo 2012; Ndour 2017). Farmers must obtain literacy and numeracy skills to adopt new methods, respond to risk challenges and market signals (Hopkins and McKeown 2002). Access to knowledge and information assists farmers in developing the ability to prevent risks (Beck 1992). Households with a higher education level can promote information and resources to improve risk perception and reduce poverty (Muttarak and Lutz 2014).

4.1.3 Human Capital Development

The human capital theory considers it a life-long process of acquiring knowledge and skill at any age in shaping peoples' lives and making it meaningful (Steve et al. 2014). According to Schultz (1961), capital acquired in pursuing education at vocational and technical levels is a product of well-considered investments to generate income. Babalola (2003) argues that a nation's human resources, not its natural capital or material resources, ultimately determine its economic and social development.

Human capital impact on agricultural productivity shows that workers' education and training results in increased productivity and income (Schultz 1961). According to Welch (1970), by developing the human capital through education and training, the farmer can significantly improve his/her work quality, use the available resources more efficiently to reduce waste, and seek channels to apply the acquired education and experiences for sustainable production (Klasen and Reimers 2011). The development in agriculture involves several innovations and adjustments to complex scientific changes, which require a more sophisticated and overall better-educated farmer to achieve sustainable agricultural production (Steve et al. 2014). Djomo (2012) further stated that the experience gained in additional training contributes significantly towards increased production.

5 Trends in Trinidad

5.1 Land Distribution

Through an official agricultural land distribution programme in Trinidad and Tobago during the past 50 years, the State allocated more than 30,000 hectares of lands with tenure for smallholder (1–4 ha) production of crops and livestock (Persad et al. 2007). Additionally, in 2003, the State allocated 12,158 ha of former sugar cane lands of Caroni (1975) Limited for diversified agricultural production after restructuring the sugar industry (Wilson 2006). Seven thousand eight hundred former employees of the sugar industry received 2-acre (0.8 ha) parcels under standard agricultural leases of 25 years to engage in a range of small-scale agricultural projects, with support in necessary infrastructure, marketing, and training (Persad 2004). These land assignment's objectives were to generate agricultural activities and promote national food security by increasing production (Inter-Agency GOTT 2004) included enhancing food production, generating agricultural activity, and promoting national food security (Inter-Agency GOTT 2004).

However, these agricultural programmes are distributed on poor soils (mainly heavy clay), challenging terrain, and generally classified as class V–VIII, which encountered many technical and economic challenges resulting in limited success (Persad et al. 2007). According to Persad et al. (2007), inadequate agricultural practices further exacerbate the challenges, with <20% of lands cultivated and <50% cultivatable. These challenges indicate that the farmers generally lack the funding and technical support necessary to achieve sustainable amelioration practices and soil management indicating that small farm holdings generally lack the technical and financial resources to achieve sustainable soil management and amelioration practices.

Further, the Parliament's Joint Select Committee dealing with Land and Physical Infrastructure (2017) reported that the sector still operates under the nineteenth-century farming methods resulting in widespread under-utilization of State lands. Several reasons account for the under-utilization of agricultural State lands, including lack of tenancy by most occupants, land management and administration system inefficiency, and an inefficient mechanism of removing State lands' squatters. The report also indicated that the challenges of developing the agricultural sector included an aging population without the willingness to embrace new methods and technology and an uninterested youth population in agriculture.

Based on these findings, the committee recommended providing the necessary infrastructure, maximizing willing farmers' innovations with additional training, and engaging youth for the agricultural sector's succession and continuity. It also incorporated SDG 2 as part of the National Action Plan to promote sustainable agriculture by engaging all stakeholders to participate in the programme. It also recommended the establishment of public/private partnerships as a strategy for sustainable development.

5.2 Marketing Support (NAMDEVCO)

In 1991, the Trinidad and Tobago Government established (NAMDEVCO) as the National Agricultural Marketing and Development Corporation (NAMDEVCO 1991). It is a Statutory Body by the Act of Parliament No. 16 of 1991. NAMDEVCO's role is to develop a sustainable and competitive marketing sector. It aims at providing safe and healthy foods to the local and international markets by building the productive capacity of farmers and providing market information for timely decision-making and marketing activities.

NAMDEVCO's mandate includes developing and maintaining a conducive environment to efficiently produce and market-fresh and value-added agricultural products. NAMDEVCO achieve this mandate by providing opportunities that stimulate marketing and investment opportunities for agricultural business development in Trinidad and Tobago (NAMDEVCO 2015b).

The Quality Assurance (QA) Department provides a "Certification and Monitoring Programme" to support certified farmers in adopting Good Agricultural Practices (GAP) to reduce wastage along the production stages (NAMDEVCO 2015a). The aim is to provide a system that enables the application and verification of controlled measures intended to assure the safety and quality of agricultural products. GAP constitutes several farming practices to achieve safe and healthy food in an economic, social, and environmentally sustainable environment (Dookie 2018).

The farm certification programme consists of approximately 2186 registered participating farmers located in 6 counties in Trinidad and serviced by 11 Field Officers (Table 1) (NAMDEVCO 2018).

5.2.1 Wholesale and Farmers' Markets

NAMDEVCO's wholesale and farmers' market outlets are in seven locations throughout the country (NAMDEVCO 2015c), Fig. 2. The location of its head office is on the compound of the Penal wholesale and retail market on the southern side of the country. Postharvest and waste management at these markets include facilities to receive and safely dispose wastes.

Table 1 Listing of registered farmers

County	Allocation of farmers
Caroni	617
Mayaro/Nariva	98
Saint Andrew/Saint David	460
Saint George	493
Saint Patrick	301
Victoria	217
Total	2186

Fig. 2 Market locations (NAMDEVCO 2015c)

Packinghouse Facility

The fresh produce Packinghouse facility is at Piarco, strategically 2 km from the Piarco International Airport, facilitating easy air transport to maintain the export market's quality requirements (NAMDEVCO 2015c). The Packinghouse is a one-stop post-harvest operation for local and foreign markets (NAMDEVCO 2015c). On average, the Packinghouse generates 2164 kg of waste per month, comprising rejects, trimmings, peelings, and spoilage which farmers use as substitute animal feed (NAMDEVCO 2018).

GreenVine Monthly Bulletin

NAMDEVCO's monthly GreenVine bulletin provides marketing information to strengthen agribusiness stakeholders' management and technical capacity (NAMDEVCO 2015c). It delivers updated marketing intelligence on the current status and outlook for developing a sustainable Agri-Food sector.

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5.3 Financial Support (ADB)

In 1968, Government established the Agricultural Development Bank (ADB) to provide significant funding for farmers and agri-business sectors in Trinidad and Tobago (ADB 2020). The ADB provides the agricultural sector with several financial choices with strategic linkages providing customer support and flexible loan payment arrangements with competitive interest and amortized rates for the sector's development. Additionally, the bank developed various loan products and services to introduce savings and investment options in response to customer and sector requirements.

6 Ro-Crops Model Farm

6.1 Background

Ro-Crops is a smallholder family farm with tenancy since 1960 for 1.5 ha of State land at plot # 23 Uquire Road, Carlsen Field, Trinidad. The farm forms part of 686 hectares of State lands agricultural project and is within a 100-acre block allocated to 30 smallholder farms averaging 1.5 ha. The farming area was a US Air Force Base (AFB) during the Second World War (WWII), from 1941 to 1949 (Wikipedia 2021). Figure 3 shows the site location. Construction of the airbase included land clearing and removal of topsoil and vegetation. The agricultural project development on this site included utilizing existing physical infrastructure and utilities from the war base, such as paved access roads, several water reservoirs, a water-treatment plant, telephone, and electricity as an integral part of the farming community.

6.2 Land Tenure and Succession

Ro-Crops has land tenure and a succession strategy through a 30-year State Land Standard Agricultural lease until 2045 with a renewal option at each expiratory date for agricultural and residential purposes. The farm family now constitute the 74- and

Fig. 3 Carlsen A.F.B., Trinidad (Wikipedia 2021)

76-years old parents with a 40-year-old son and daughter-in-law of similar age plus a 5-year old son as the successors. The farmstead has been the family's home for the past 36 years, providing the principal income source.

6.3 *Ro-Crops Core Business*

Although development work started in 1985, Ro-Crops was registered as a Partnership Business in 1996 as 'Ro-Crops Agrotec.' It is certified on NAMDEVCO's Farm Certification Programme in compliance with Good Agricultural Practices (GAP) for sustainable agricultural production (NAMDEVCO 2010). Its core business is producing and marketing a selection of tropical fruits and vegetables in an integrated sustainable management system utilizing innovative soil and micro-irrigation technology. It provides the well-known 'Ro-Crops' brand of quality fresh fruits and vegetables with traceability to the source of production. Ro-Crops supplies fresh limes with attractive packing to leading supermarkets in Trinidad (Fig. 4).

Fig. 4 Ro-Crops lime and labels

6.4 Ro-Crops Accomplishments

In June 2021, the farmer received The Inter-American Institute for Cooperation on Agriculture (IICA) Hemispheric "Soul of Rurality" Award. IICA bestowed this award on Rurality Leaders in the Americas for building resilience to climate change in family farming (IICA 2021). At the 2001 National Agricultural Awards in Trinidad, Ro-Crops won 1st Place in Integrated Agriculture and the Agricultural Entrepreneur of the Year Award (STAN 2002).

Internationally, Ro-Crops farm is on the FAO's Agroecology Knowledge Hub as one of "52 Profiles on Agroecology" (FAO 2016); it is a Global Water Partnership—Caribbean partner seeking a water-secure world (GWP-C 2011) and an advocate for Climate-Proof Farming in building resilience to climate change (IPS 2013).

The farm is one of three family farms in Trinidad honoured in 2013 by IICA and the Regional Fund for Agricultural Technology (FONTAGRO) for implementing innovative agricultural practices for sustainability (Guardian 2013). The farmers participated in the competition on success cases in innovation for the family agriculture 2012 contest. The FONTAGRO fund supports the alliance of Latin American and Caribbean countries for agriculture research and innovation to reduce poverty, promote competitiveness, and sustain natural resources (FONTAGRO 2021). Ro-Crops presented the case on an integrated system for rehabilitation of degraded acidic, heavy clay soils for horticultural production with minimum external inputs to manage pests, diseases, soil, and water in an economically feasible and environmentally friendly system.

6.5 Ro-Crops Development

6.5.1 Pre-lean Implementation (1985–1994)

The early farming practices from 1985 to 1994 consisted of sugarcane cultivation and subsistence cropping under rain-fed conditions resulting in losses due to uneconomical yields and low productivity. The soil type is heavy long stretch clay with 3.5 pH consisting of degraded sugarcane lands (Persad and Wilson 1998). According to Virmani et al. (1982), heavy clay soil has high field capacity with poor internal drainage, low hydraulic conductivity, and infiltration, resulting in waterlogging and flooding in the wet season. Bai and Dent (2006) state that farming under these conditions often resulted in low production, uneconomical yields, with a waste of natural, non-renewable, and human resources, which contribute to environmental degradation. Figure 5 shows Ro-Crops initial farm layout for subdivision into eight (8) farming blocks.

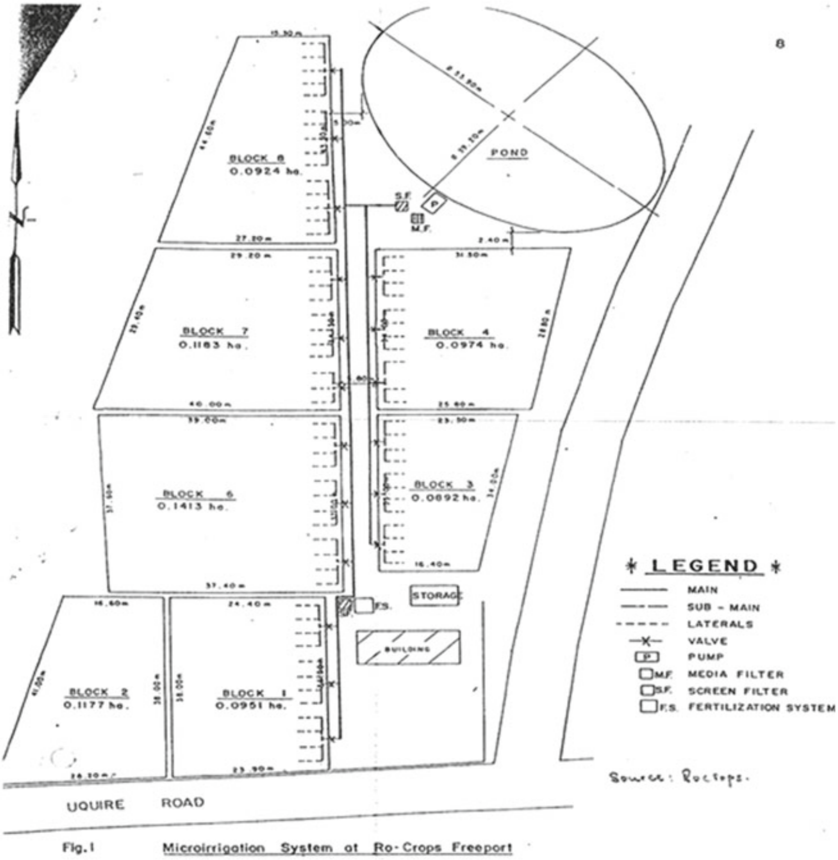

Fig. 5 Initial farm layout

6.5.2 Implementing Lean (1994–1997)

With a desire to reduce waste, maximize efficiency and increase production, this period focused on establishing an alliance with the Ministry of Agriculture to conduct on-farm research and data generation. The aim is to transform the existing farm from subsistence cropping into an efficient and environmentally friendly sustainable unit. The Rocrops family had the educational background and prerequisite requirements to access the Agricultural Development Bank (ADB) funding to undertake the project.

During 1994–1997, the soil scientist and fellow researchers of the Ministry of Agriculture conducted on-farm research on soil and water management. Two research papers documented the results on managing heavy clay soils (Persad and Wilson 1998) by utilizing and evaluated a micro-irrigation system for vegetable production on heavy clay soils in Central Trinidad (Persad and Roop 1998).

6.5.3 Lean Management in Soil and Water Soil Management

The project demonstrated that implementing low input soil management techniques could ameliorate clay soils for intensive vegetable production in Trinidad as a lean strategy. Data from the soil management research (Persad and Wilson 1998) show the land reformation consisted of soil amelioration initiatives using low-cost quarry overburden limestone, subsoiling, and tillage improved the soil's physical surface conditions and subsurface drainage. As a result of these measures, the soil pH increased to 6.38 from the initial 3.98 pH within one year. These pH values were sustained at near 6.50 levels by regular soil testing and corrections. It is best to achieve a pH value of 6.5 for a wide range of vegetable crops grown on small farms to reduce the wastage of agricultural inputs and increase productivity. The results also showed a marked improvement in crucial soil fertility parameters with increased phosphate, potassium, calcium, and magnesium, increasing fertilizer efficiency and reducing wastage.

6.5.4 Water Management

Data from the water management research (Persad and Roop 1998) also shows that the application of micro-irrigation systems improved crop yields and quality, especially in heavy clay soils, with water use saving and efficiency. A critical aspect of micro-irrigation is the potential to produce high-value crops with control over the production cycle, land-use efficiency, increase yield, productivity, profitability, and fertilize crops more effectively. Using the micro-irrigation and fertigation system at Ro-Crops in the dry season reduced water wastage, resulting in approximately an 80% increase in marketable vegetables.

Establishing the irrigation system included redesigning the farm layout in compliance with the lean concepts by constructing internal access roads, establishing a (56 m × 39 m × 5 m) by-pass irrigation pond with a holding capacity of 10,000 m^3 of water and an independent fertilization station. The field layout design included subdivision of the 1.5-ha holding into eight (8) irrigation blocks (7 for cultivation), with the farm pond as block 5. Construction of the access roads facilitated the drainage and water harvesting, reducing wastage by recycling field water into the irrigation pond. The internal access roads also allow easy movement of farm vehicles for field maintenance and harvesting to reduce postharvest losses and wastage. The complementary irrigation and fertility practices and cropping patterns formed part of the integrated strategies to increase overall farm production, productivity, and profitability by reducing waste at the production stage.

Further farm development included constructing a permanent steel and concrete two-story family dwelling house (55 ft × 45 ft), storage and postharvest buildings, and upgrading the water storage pond, micro-irrigation system, access roads, and peripheral fencing. The new farm layout consists of lean implementing measures of 'flow and coverage' of farm activities to reduce movement on the farm as part

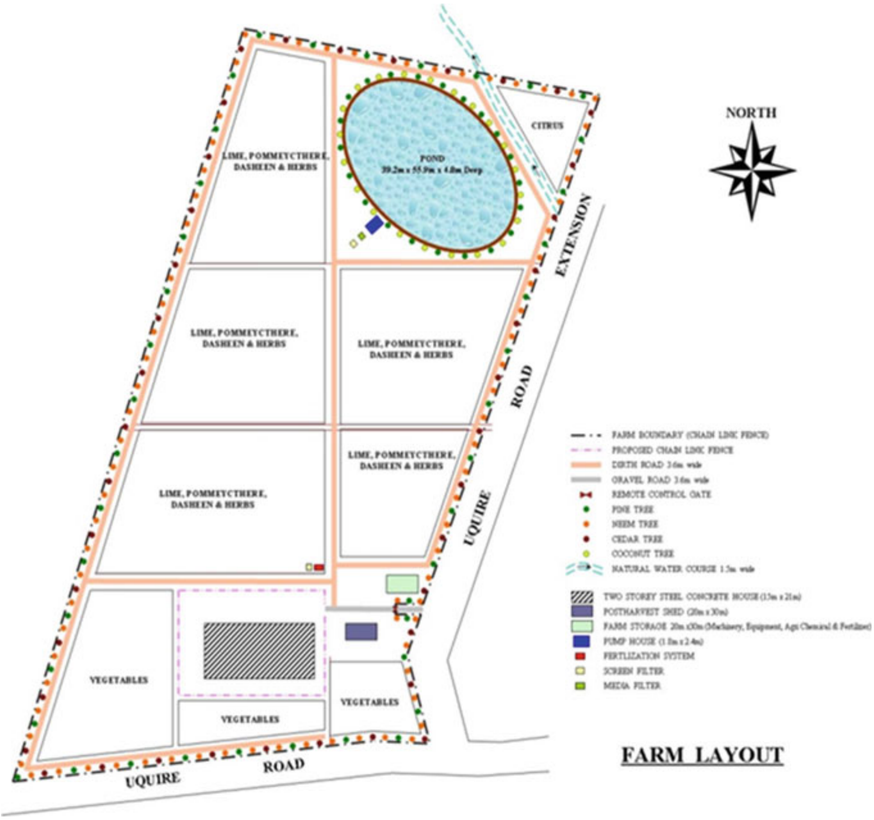

Fig. 6 New lean farm layout

Fig. 7 Farm pond and filtration

Fig. 8 Micro-irrigation system

Fig. 9 Access road

of the lean strategy (Fig. 6). Figures 7, 8, and 9 show the Farm pond and filtration; Micro-irrigation system; Access road.

6.5.5 Sustainable Lean Development (1997–2021)

The post-1997 to 2021 period focused on strategic business management processes and sustainable food and nutrition security development. These management processes focused on entrepreneurship, business registration, land tenure, succession, and developing human capital. External connections included participation in farmers' organisations and establishing alliances with local, regional, and international organisations. The crop production strategies changed from vegetable monocropping to integrated tree crops (Limequat and Tropical fruits) with low-input production, agroecological and conservation farming, and Integrated Crop and Pest Management (ICPM). These measures resulted in producing throughout the year high-quality pesticide-free agricultural products. The harvesting method included

Fig. 10 Harvesting limes

collecting the limes in a back-sack and stored in a ventilated vehicle to minimise post-harvest losses, as shown in Fig. 10.

6.5.6 Integrating Lean with Agroecology

In consultation with the Ministry of Agriculture researchers, the farm management adopted a diversified farming system that includes functional biodiversity through traditional and agroecological scientific knowledge. This system included integrated cropping of vegetables, herbs, spices, lemongrass, tropical fruits, with limes as the commercial crop. It also incorporated non-cropping trees around the borders as live fencing and hedgerows. These trees are planted as windbreaks creating a microclimate less conducive to pest and disease proliferation and providing shade for vegetable crops. The windbreak trees included the Caribbean pine (*Pinus caribaea*), Colombian cedar (*Cedrela odorata*), ornamental bougainvillea (*Bougainvillea glabra*), variegated bamboo (*Bambuseae multiplex*), and neem (*Azadirachta indica*). The nitrogen-fixing "fertilizer trees" complemented and enhanced commercial fertilizer, improving crop yields and rain-use efficiency (Sileshi et al. 2012). Figure 11 shows trees along the access road and perimeter fence.

The Integrated Crop and Pest Management (ICPM) practices on the farm included applying organic manure and mulch to protect the soil structure and stability. These measures contribute to improved water retention and increase fertilizer efficiency in the dry season. Weeds control measures include using motorized hand-held brush cutters and hand-weeding with the cuttings left as a mulch for moisture retention, especially during the dry season. Field sanitation and exceptional attention to postharvest handling techniques became strategies for integrating lean management in the farming system.

Fig. 11 Caribbean pine and variegated bamboo along the access road

6.5.7 Lean in Strategic Alliances

The UN Sustainable Development Goals (UN 2015) called for multi-stakeholder partnerships, including farmers, companies, governments, and civil society, in achieving sustainable agricultural development.

Ro-Crops has demonstrated that its sustained and equally rewarding technical relationship in 1994–1997 with the Research Division of the Agriculture Ministry, has contributed to its sustainable development. During the past 26 years, it has also formed relationships with other local, regional, and international organizations and businesses. Its interaction with farmers' groups and the universities of The West Indies (UWI) and the University of Trinidad and Tobago (UTT) provides on-farm training and demonstration for farmers, Extension Officers, environmental and agricultural secondary school students, Figs. 12 and 13. The understory of the family dwelling house serves as an agricultural training centre. These training sessions demonstrate practical hands-on experience on various best management practices emphasizing lean as a scientific concept (Spear and Bowen 1999), emphasizing learning as a central component of the process (Holweg 2007).

Fig. 12 Training sessions for extension officers and environmental students

Fig. 13 Training session A-level environmental students

6.5.8 Human Capital Development

Ro-Crops family understands the importance of education, life-long learning, and human capital development with the three children (sons) and their wives attaining tertiary education. The farmer's wife received secondary level education with extensive training in agriculture and agribusiness. The household head advocated the importance of lifelong learning and demonstrated that it is Never Too Old to Learn by acquiring two master's degrees in Business with distinctions at 69 and 71 years (Gates 2017; GWP-C 2019). He desires to share this knowledge as a mechanism of achieving sustainable agriculture and food security. Additionally, in 2020, he contributed a chapter on climate change as the lead author for Springer's Handbook on Climate Change Management: Research, Leadership, Transformation (Roop and St. Martin 2020). As an advocate for lifelong learning, it influences developing the human capital beyond the farmer, family, and workers.

7 Conclusions

The research demonstrates the existence of a lack of literature on lean management in agriculture and farming. Therefore, introducing the lean concept is necessary because the sector generates large amounts of waste and losses at different production levels (Dora et al. 2015). There is great emphasis on increased production with limited focus on sustainability (Rockström et al. 2017). However, the complementary factor of reducing loss and waste is often ignored as a sustainable strategy to achieve food and nutrition security (Hodges et al. 2011). The "losses" in the food industry exists along the supply chain at production, post-harvest, and processing operations (Parfitt et al. 2010). These losses result from inadequate harvesting technologies, untimely transport, and improper storage (Papargyropoulou et al. 2014).

Smallholder farms experience a considerable amount of postharvest loss due to inadequate market facilities without access to refrigeration storage (Hodges et al. 2011; Tefera 2012). According to Dobermann and Nelson (2013: 2), the food systems and agricultural require a more productive, resource-efficient, resilient, and less wasteful system. The lean production concept promotes a desire to achieve waste reduction, maximum efficiency, and increased economic value due to productivity, quality, and flexibility as the primary performance indicators (Krafcik 1988). Therefore, this paper examined integrating lean management concepts in smallholder farming as a catalyst to achieve sustainable agriculture and food security.

The paper also examined trends in Trinidad, which show that the distribution of agricultural lands is also on poor soils (mainly heavy clay), challenging terrain, and generally classified as class V–VIII, which encountered many technical and economic challenges resulting in limited success (Persad et al. 2007). According to Persad et al. (2007), inadequate agricultural practices further exacerbate the challenges, with < 20% of these lands cultivated and < 50% cultivatable indicating that smallholder farms generally do not have the necessary technical and financial resources to achieve soil and amelioration management practices. Further, the Parliament's Joint Select Committee on Land and Physical Infrastructure (2017) reported that the sector still operates under the nineteenth-century farming methods resulting in widespread under-utilization of State lands.

The research shows that fosters a sustainable and competitive agricultural sector (NAMDEVCO 1991). It established several programmes to provide safe and healthy foods to the local and international markets by building farmer's capacity, and providing timely decisions-making and marketing services.

Additionally, the ADB provides a significant funding source for developing Trinidad and Tobago's agricultural and agro-business sectors (ADB 2020). The services include several financial options with strategic linkages to support the customer with flexible payment terms. The ability to access capital for investment enables farmers to become resilient and sustainable (Thulstrup 2015).

The literature indicated several constraints and challenges which smallholder farmers encounter in achieving sustainable agricultural development. These include land tenure and succession, accessing capital, production challenges, postharvest management, social and environmental constraints. Hicks et al. (2012) identified succession as one key mechanism for food and nutrition security. **Additionally, education is the most significant resource to achieve a just and ecological society** (Schumacher 1973, p. 64) **and an essential tool in achieving sustainability** (Hopkins and McKeown 2002).

Ro-Crops case study shows that land tenure, succession planning, building strategic alliances, and human capital are essential prerequisites for implementing lean concepts to achieve sustainable agriculture and food security.

Recommendations

Developing the agricultural sector in Trinidad and Tobago requires incorporating the Joint Select Committee's findings. The recommendations included providing the necessary infrastructure, maximizing willing farmers' innovations with additional training, and engaging youth for the agricultural sector's succession and continuity. It incorporated SDG 2 as part of the National Action Plan to promote sustainable agriculture by engaging all stakeholders to participate in the programme. It also recommended establishing public/private partnerships to explore modern farming techniques to enhance farmer's training. The case study of Ro-Crops is an example of a willing private partner, which demonstrates that integrating lean concepts in small-holder farming is an effective catalyst to achieve sustainable agriculture for food and nutrition security. The management of Ro-Crops demonstrates that sustainable agriculture and food security are achievable through strategic and succession planning, farm management, and applying innovative waste removal measures without the process of it becoming an obsession.

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Reducing Food Loss in Kenya for a Sustainable Food Future

Fiona Nyawira Mwaniki and Florence Kiragu Nyamu

1 Introduction

Attainment of a sustainable food future is a desirable goal globally. To ensure a sustainable food future requires a multi-pronged approach involving all actors in the food value chain. This is necessary so as to meet the nutritional needs of an increasing world population as well as to achieve individual country and global targets. The 2020 World Population Data Sheet projects an increase of the global population up to 9.9 billion people by 2050. Meeting the nutritional needs of the rising population entails providing a balance between competing priorities for policy makers, researchers and practitioners. This is important if countries are to achieve the 17 Sustainable Development Goals (SDGs) adopted by the United Nations in 2017 and set to be achieved globally by 2030. Goal No. 2 of the SDGs is *Zero Hunger*, whose aim is to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (United Nations Development Agency 2021).

Discussion of food and agriculture at the international level increased in the early decades of the twentieth century, culminating in an international conference on food and agriculture held in Quebec, Canada in 1945 (FAO 2013; Phillips 1981). It was at this conference that the Food and Agriculture Organization (FAO) of the United Nations was established with the express mandate to '*improve nutrition, increase agricultural productivity, raise the standard of living in rural populations, and contribute to global economic growth*' (Phillips 1981). The focus for FAO is to achieve a world that is food-secure, free from hunger and malnutrition.

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The Malabo Declaration adopted by the African Union in 2014, provides direction for Africa's agricultural transformation for the period 2015–2025. The African Union expects all member states, including Kenya, to reduce food loss by at least 50% by the year 2025. However, as of 2018, only five countries, Malawi, Mauritania, Rwanda, Togo and Uganda, were on track to achieve this target (African Union 2018). The recommendations made to member states included the need to increase funding for agriculture, increase of financial and advisory services for men and women engaged in agriculture, and improvement of data systems to enhance accountability.

The 1996 World Food Summit posited that '*food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life.*' (FAO 2021). Rwanda, which in 2018 was rated the best performer in achieving the commitments set out in the Malabo Declaration, initiated ongoing agricultural programmes aimed at increasing productivity in value chains for dairy and for common crops like maize and beans. According to Fraanje and Lee-Gammage (2018), one condition favouring food security is the availability of food. This relates to the continuous presence of safe and nutritious food to a community or a country. Another condition is access to food such that an individual or a household is able to buy or barter for food. A further component is food utilisation which is concerned with the ability of the body to utilize the nutrients in the food. For a society to develop and sustain itself, its people must lead a healthy life and obtain important nutrients in the right amounts for maximum productivity.

It is estimated that 25% of Kenya's population suffers from chronic food insecurity, a situation that has prompted the government to provide food aid to 5% of the population and to import food at an estimated cost of USD 1.3 billion annually (Mutungi and Affognon 2013). To facilitate increased food production, Kenya has developed policies and programmes to address food security. In the paper, *African socialism and its application to Kenya*, published in 1965, it was emphasized in clause 102, that '*development in agriculture will be given first priority in the African areas*' (Republic of Kenya 1965). The first National Food Policy (Sessional Paper No. 4 of 1981), was later integrated into Sessional Paper No. 1 of 1986 on Economic Management for Renewed Growth, with a view to maintaining self-sufficiency and equitable distribution of nutritional food. The Agricultural Sector Development Strategy (ASDS) (2010–2020), was the national policy document for the sector ministries and all stakeholders in Kenya. The three most recent policies are the National Food and Nutrition Security Policy (FNSP) Implementation Framework (2017–2022), the National Agriculture Investment Plan (NAIP) (2019–2024), and the Agriculture Sector Transformation and Growth Strategy (ASTGS) (2019–2029).

The National Food and Nutrition Security Policy (FNSP) (2017–2022), was enacted to enhance the Strategic Food Reserve through promotion of public–private partnerships to handle post-harvest processes. The policy aims to increase food security and nutrition through increased productivity and income growth, commercialisation, equitable distribution of produce, and environmental sustainability. The National Agriculture Investment Plan (NAIP) (2019–2024), and the Agriculture Sector Transformation and Growth Strategy (ASTGS) (2019–2029), are premised on achieving 100% food and nutrition security in the 47 counties of Kenya through the creation of a commercial and technology-savvy agricultural sector. NAIP and ASTGS are aligned to the County Integrated Development Plans (CIDPs) and the national Medium-Term Plans (MTPs), the Malabo Declaration of 2014, and the SDGs. The ultimate goal is to eradicate hunger and improve nutrition while ensuring the fundamental right to food. In order to meet this goal, it is necessary to discuss food loss and ways of mitigating it.

Food loss refers to any reduction of edible food mass or nutritional value along the food supply chain from harvest up to but not including the retail level. Food loss also refers to reduction in quantity and quality of any produce that is considered safe for human consumption (FAO 2014). Food loss and waste are a global concern and have emerged as a priority in the national and global political agenda. In developing countries, food losses arise from financial, managerial and technical constraints at early stages during harvesting, post-harvest storage, and cooling stages. In medium- and high-income countries, the behaviour of consumers plays an important part in food loss especially at later stages in the supply chain.

It is a matter of great concern that food losses occur even as 12.9% of the population in developing regions suffers from hunger and malnutrition, and have limited access to adequate quantities of food of high nutritional value (UNEP 2021). It is expected that the world population will grow to more than 9 billion by 2050, hence increasing the demand for food by 60% (UNEP 2021). According to Kwasek (2013), there are six threats to future food security. These are: (a) rapid growth in world population; (b) increased demand for food; (c) escalating food prices; (d) loss of a variety of agricultural plant species; (e) water scarcity and limitation of available land; and (f) food losses and waste.

The focus of this paper is on food loss with regard to drivers, impacts, mitigation strategies, and possible approaches to its reduction. The paper is a review of literature with the overall purpose of investigating the impact of food loss on the attainment of a sustainable food future for Kenya. The objectives are: (i) to document drivers of food loss in the agricultural value chain; (ii) to assess the impact of food loss on the achievement of a sustainable food future; (iii) to document strategies in use for mitigating food loss; and (iv) to make suggestions on approaches to reduce food loss. The review is guided by a hypothesis that reduction of food loss is a strategy that can contribute towards the achievement of zero hunger and a sustainable food future. The paper outlines the methods used in conducting the literature review, the results and discussion, conclusions and recommendations.

2 Methods

This paper is a review of literature focusing on both qualitative and quantitative data. The reviewed articles were from the period between 2012 and 2021 and were identified from books, peer-reviewed journals, reports, policy documents and websites of

Table 1 Articles analysed for each objective

Objective	Sources of information
Document drivers of food loss in the agricultural value chain	Affognon et al. (2015), African Union (2018), FAO (2020a), Kansiime et al. (2021); Malhi, Kaur and Kaushik (2021), Kimatu et al. (2012), Kwasek (2013), Mobolade et al. (2019), Mujuka et al. (2020), Njaramba and Munene (2020), O'Neill et al. (2017), Parliamentary Budget Office (2020), Salih et al. (2020)
Assess the impact of food loss on the achievement of a sustainable food future	Affognon et al. (2015), Amusan and Ajibola (2019), Colbert (2015), Daminger et al. (2016), Gromko and Abdurasolova (2021), Kimatu et al. (2012), Liebetrau (2019), Mobolade et al. (2019), Omara et al. (2021), Mutungi and Affognon (2013), Principato et al. (2019), Ritchie (2020), Tarus (2019), UNEP (2021)
Document strategies in use for mitigating food loss	Affognon et al. (2015), Agricultural Sector Development Strategy (2010–2020), Dunnin (2020), FAO (2020b), KALRO (2021a, b), Mahmoud (2018), Mobolade et al. (2019), Mujuka et al. (2020), Nwaigwe (2019), Omara et al. (2021), Shieber (2020), Taimba (2020), TEVEL (2020), Thunde and Baulch (2020), UN Women (2021)

agencies and organisations that operate in the agricultural sector. The search for articles was guided by the search words "*post-harvest losses in sub-Sahara Africa*", "*food loss*", "*impact of food loss*", "*drivers of food loss*", "*threats to food security*", "*climate change and agriculture*", "*food loss and greenhouse gas emissions*", "*sustainable development goals*", "*threats to food security*", "*sustainable food future*", "*policies on agriculture and food in Kenya*", "*food loss mitigation*", "*COVID-19 implications to food security*", "*agriculture sector and food economy*", "*interventions for mitigating food loss*", "*research in food loss.*" For analysis, the search was further narrowed to articles that contained relevant information to the objectives and the hypothesis of the study. Table 1 shows the articles that were analysed for each objective.

2.1 Data Analysis

Data from the reviewed articles were analysed using steps outlined by Creswell (2014) as follows: (i) familiarisation with the data; (ii) coding; (iii) generating themes; (iv) reviewing themes; and (v) naming themes. The data were thematically coded using an inductive approach. This meant that the themes emerged from the data (Gray 2014). The themes captured important aspects about the data in relation to the objectives (Gray 2014). The process of inductive analysis involved the discovery of patterns, themes, and categories (Patton 2002). The information from the data analysis was collated and synthesised according to the objectives.

2.2 Results and Discussion

In this section, the results of the literature review are presented and discussed based on their implications with regard to reduction of food loss. The presentation of the results in this section is aligned to three objectives of the study and presented as: (a) drivers of food loss; (b) impact of food loss; and (c) strategies in use for mitigating food loss. The results of the fourth objective, to make suggestions on ways of reducing food loss, are presented in the conclusions and recommendations section.

3 Drivers of Food Loss

The drivers of food loss can be grouped into four categories: climate change, nature, human activity, and policy.

3.1 Climate Change

Climate change is regarded as a driver of food loss due to its impact on agriculture with regard to increased disease incidence, varying rainfall patterns and floods, droughts, and emergence of new diseases (Malhi et al. 2021; O'Neill et al. 2017). The frequent droughts and floods that occur as a result of climate change have negatively affected the production and distribution of food resulting in food loss and an erosion of livelihood opportunities and community resilience. In July 2011, Kenya suffered the worst food insecurity situation in sixty years, where an estimated 2.4 million persons required food and non-food aid (Kenya Food Security Steering Group, February 2011). This was as a result of a drought that caused more than 3.5 million (approximately 10% of the population) to face starvation (KIPPRA 2011). It is evident that climate change impacts on agriculture, and ultimately on food loss. However, efforts can be made to mitigate the effects of climate by putting in place mechanisms for water harvesting, use of weather forecasts, placing emphasis on afforestation, and improving road infrastructure for easy transportation of food from food-surplus to food-deficient areas.

3.2 Nature

Natural drivers of food loss include pests, diseases, and pathogens that attack crops growing in the field or harvested produce in storage. In some cases, natural drivers are made worse by climate change. For example, according to Salih et al. (2020), the desert locust invasion reported in northern Kenya in 2019, was facilitated by the winds of Pawan, a tropical cyclone. This was the worst desert locust invasion in Kenya in 70 years and placed at risk the food security of nearly 3 million vulnerable households. The agro-pastoral communities were hardest hit because they were already experiencing a period of prolonged drought (FAO 2020a). The risk of food insecurity was exacerbated by the announcement of the presence of COVID-19 in the country in March 2020. The containment measures for COVID-19 included the immediate closure of facilities in the education sector and the hospitality industry, restricted inter-county movement, and a 7 p.m.–5 a.m. curfew (Kansiime et al. 2021). These measures led to a drastic reduction in movement of food, a decrease in food demand and an increase in food prices (Siche 2020).

The findings indicate that damage from natural drivers can only be prevented by putting in place mechanisms for disaster preparedness and response at the community level. The three mechanisms that would bear fruit are: (a) reinvigorating committees on disaster preparedness; (b) undertaking research with an emphasis on pests and emerging diseases; and (c) educating farmers on the disasters and opportunities for local response.

3.3 Human Activity

Human activity as a driver of food loss relates to poor decision-making along the food value chain. For example, inappropriate decisions on the management of strategic food reserves, limited market access, improper food handling and storage for major food commodities, have an impact on food loss (Affognon et al. 2015). Poor road infrastructure, which is prevalent in many parts of Kenya, becomes an impediment to distribution and marketing of food mainly during the rainy seasons (Mujuka et al. 2020). Unsuitable storage facilities create opportunities for pests to invade the food, rendering it unfit for human consumption (Mobolade et al. 2019). Poor decision-making along the value chain may be a result of inadequate finances, limited knowledge, training and exposure, and insufficient coordination between the various actors involved.

3.4 Policy

Gaps in policies and their implementation, are also drivers of food loss. Kenya is committed to allocate a minimum of 10% of the national budget to agriculture in accordance with the provisions of the African Union Maputo Declaration of 2003, the Malabo Declaration of 2014 and the guidelines in the Comprehensive African Agriculture Development Programme (CAADP) (African Union 2018). Besides allocating a minimum of 10% of the national budget to agriculture, Governments are expected to work towards maintaining an average annual growth rate of 6% productivity in agriculture. However, an analysis of the national budget allocation for agriculture for the period 2014–2021 shows that Kenya has not been able to meet this target (Fig. 1).

It is evident that the budgetary allocation for agriculture from 2014 to 2021 is less than the 10% required by the Maputo Declaration and the allocation for agricultural research is even lower (Fig. 1). The budgetary allocation for agriculture declined from USD 628 million in the financial year 2014/2015, to USD 480.9 million in the financial year 2020/2021.

Evidence from the literature shows that implementation of policies in Kenya has not been fully achieved within the projected time frame. The Kenya Agricultural Sector Development Strategy (ASDS) intended for the period 2010–2020, was set to achieve food security and make Kenya a prosperous nation by 2020. At the time of writing this paper in March 2021, the objectives had not been achieved. Several factors such as floods, recurrent drought, locust invasion, and food loss may have contributed to the slow implementation.

A significant contributor to slow implementation of projects and programmes is a lower than targeted revenue collection compared to high expenditures for the third Medium Term Plan programmes and projects (Parliamentary Budget Office 2020; Njaramba and Munene 2020). Other factors such as digital taxes which came into

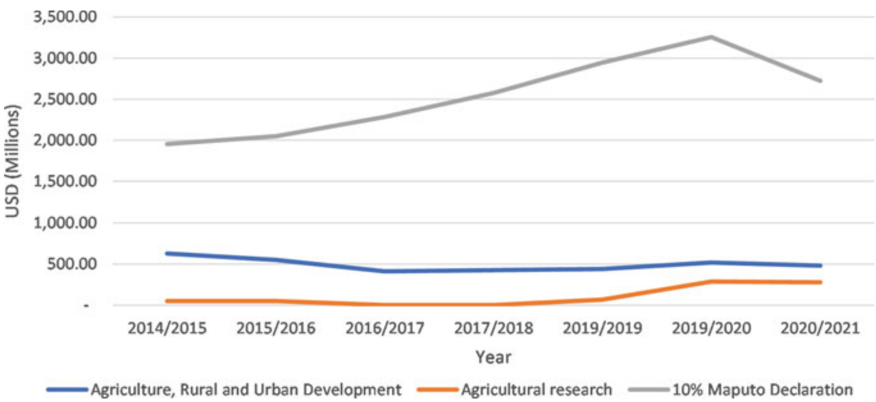

Fig. 1 Budgetary allocation for agriculture, rural and urban development, and agricultural research (2014–2021). *Sources* Parliamentary Budget Office (2020), Njaramba and Munene (2020)

effect in January 2021, further compound this challenge. The taxes include a 1.5% Digital Service Tax (DST) vide the Finance Act 2020 and a 1% Turn Over Tax (TOT) vide the Finance Act 2019. The national and county governments need to improve the regulatory environment in order for enterprises in the food loss space to thrive and be sustainable. It is clear that ensuring food security will require substantial investments and actions to reduce effects of climate change, nature and human activity and to ensure enactment of policies favourable to agriculture as the mainstay of the country's economy.

4 Impact of Food Loss

It is estimated that 30% of the food produced worldwide is lost or wasted every year and 10% of stored grain is also lost annually (Principato et al. 2019; Affognon et al. 2015). High cosmetic requirements for fresh produce result in the loss of 50% of harvests during sorting and grading to meet market standards (Colbert 2015). Furthermore, cancellation of orders by retailers has often resulted in dumping of entire harvests. In sub-Saharan Africa, food loss is estimated to be 20% for cereals, legumes and pulses, 40% for roots and tubers, and 50% for fruits and vegetables (Daminger et al. 2016). Furthermore, 25–40% of food grain losses occur at the farm level (Mobolade et al. 2019). Losses that occur during storage are responsible for 7.5% of food losses during post-harvest operations (Mobolade et al. 2019).

An estimated 20–40% of food grown in Kenya is lost (Liebetrau 2019). The government estimates post-harvest losses at 20%, with nearly 50% of harvested fruits and vegetables lost even before they reach the market (Gromko and Abdurasolova 2021). An assessment of the food situation in 2017 showed that Kenya produced 37 million bags of maize, of which 12% was estimated to have been lost post-harvest due to pathogens, insects and rodents (Tarus 2019). High aflatoxin levels contribute to losses in maize production (Omara et al. 2021; Kimatu et al. 2012). It is estimated that 25% of Kenya's population suffer from chronic food insecurity.

Globally, food loss represents a waste of valuable resources such as water, energy, land, labour, agro-chemicals, and capital. In addition, food production accounts for 26% of global Greenhouse Gas (GHG) emissions, while 6% of global GHG emissions come from food losses and food waste (Ritchie 2020). Food loss results in financial loss to producers, exporters, and farm workers. The effects of these losses affect weak actors by reducing incomes and leading to debt (Colbert 2015). The losses have resulted in negative psychological effects on individuals, with some cases leading to suicide (Amusan and Ajibola 2019). It is clear that food loss impacts on human life, the environment, the economy, and reduces the opportunity to achieve SDGs of *No Poverty* and *Zero Hunger*.

5 Strategies in Use for Mitigating Food Loss in Kenya

The strategies that Kenya has adopted to reduce food loss and its impact are discussed in relation to innovative technology applications, cold storage, mobile-based applications, on-farm technologies, packaging technology and value addition.

5.1 Innovative Technology Applications

The use of technology in reducing food loss is gaining momentum. The literature reviewed showed two initiatives that have been developed and are in use. The first initiative is the creation of the Flying Autonomous Robots developed by Tevel Aerobotics Technologies to harvest ripe fruits (TEVEL 2020). The technology responds to a challenge of reduced human fruit pickers that arose as a result of COVID-19 safety regulations and travel restrictions. The robots which work 24 h a day, can be used in any terrain and are ready for hire by farmers. The robots work by detecting ripening fruit amidst the foliage and picking it using a robotic arm.

The second initiative is a preservative technology developed by an American-based company, Apeel Technology, to prevent fruits and vegetables from rotting (Shieber 2020). A single run of Apeel's technology is capable of treating 10,000 kg of produce in one hour. The technology is expected to keep food fresh for longer, and to prevent food loss and waste. It is in use and is being rolled out in several countries, including Kenya.

5.2 Cold Storage

The off-grid cold storage that offers reprieve to farmers is another innovation discussed in the literature. Two innovations in this category are discussed in this section. The first one is by SokoFresh which provides rentable cold storage facilities near farmers' fields. SokoFresh also connects farmers with buyers through an online platform (SokoFresh 2021). The second innovation is a mobile, solar powered cold room from a company known as Solar Freeze (Dunnin 2020). The company has developed a messaging application and notification to help smallholder farmers and traders to locate the nearest cold storage unit. Mobile cash payments make it convenient for farmers to pay for storage services at affordable rates. Refrigerated transportation to smallholder farmers facilitates movement of produce more frequently and affordably while reducing produce loss. The availability of cold storage is a boost to measures to avert food loss in Kenya, given that only approximately 20% of Kenyans living in the rural areas are connected to electricity (Mujuka et al. 2020).

5.3 Mobile-Based Applications

The use of smartphones has become more prevalent due to their increased affordability and availability. From the literature reviewed, three examples of mobile-based applications were selected for inclusion in the study. The first example is from the Kenya Agricultural and Livestock Research Organization (KALRO) which has developed applications that farmers use to mitigate food loss. One of the applications is the Kenya Agriculture Observatory Platform (KAOP) which provides up-to-date weather information for better planning of farming activities as well as other crop advisories. Other applications that have been developed by KALRO to reduce food loss are used for crops such as avocados, cashew nuts, coconuts, cassava, maize and mangos. The organisation has also developed an application to control food loss arising from fall armyworm and Maize Lethal Necrotic Disease (MLND) (KALRO 2021a).

The second example is from Twiga Foods, which has initiated a mobile-based platform that connects 3000 food outlets with fresh produce on a daily basis. The company has achieved this through a network of 17,000 farmers, over 4000 suppliers and 35,000 vendors. This platform makes it possible for restaurant vendors to purchase according to need and increases the likelihood of farmers to deliver produce more efficiently (FAO 2020b). Through this model, Twiga Foods has reduced post-harvest losses for farmers using their platform from 30% to just 4% (FAO 2020b).

The third example is from Taimba, a company which uses mobile applications to link small-holder farmers to urban traders (Taimba 2020). The company focuses on reducing food loss for potatoes, onions, tomatoes and carrots, which have a short shelf-life and are vulnerable to market price volatility. This is achieved by shortening the supply chain through direct delivery to traders.

Smartphone applications provide a simple and easy way to reach more people and different markets. They also significantly reduce movement of food and result in a reduction in the costs of production and food loss due to minimal handling during transportation. The increased use of smartphone applications was witnessed during the lockdown period after the COVID-19 pandemic hit Kenya in March 2020.

5.4 On-Farm Technologies

(i) ***Aflatoxin control***

Inadequate storage and processing facilities, coupled with poor handling, have led to the damage of a substantial amount of food grain through contamination by aflatoxin produced by *Aspergillus flavus* fungus (Omara et al. 2021; Affognon et al. 2015). In 2010, a total of 207,000 tonnes of maize containing unsafe aflatoxin levels in Kenya, were declared unfit for consumption (KALRO 2021b). In 2014, KALRO set up a modular manufacturing plant to produce *Aflasafe* in Katumani, Machakos county. *Aflasafe*, reduces levels of aflatoxin contamination in crops and ensures that food meets public safety standards as required for exportation. The product works best in combination with other good practices such as proper drying and storage. It has been observed that *Aflasafe* is cost-effective, provides health benefits and high returns on investment. Farmers who applied *Aflasafe* in maize fields reduced aflatoxin by between 80 and 99% (KALRO 2021b).

(ii) ***Safe grain storage***

Over time, several technologies that improve grain storage at household level have become available to farmers. The most commonly used technology for grain storage is sealed hermetic bags. These are airtight bags that prevent air or water from getting into the grain. The hermetic bags, considered practical and cost-effective in Kenya, preserve the contents by depleting oxygen supply and producing carbon dioxide which is harmful to pests. A similar technology is the use of metal silos. These are cylindrical structures, constructed from galvanised iron sheets and hermetically sealed, killing any insect pests that may be present. Also in use are heavy moulded-plastic containers which apply the same principle as metal silos and are less expensive.

Another innovation aimed at reducing food loss is the Warehouse Receipt System (WRS) (Thunde and Baulch 2020). This system enables owners of commodities such as cereals and grains, who may be producers or dealers, to deposit their produce in certified warehouses. The warehouse manager issues the farmer with a title document that can be used as collateral to access credit from participating financial institutions or for trading in commodity markets. This reduces the pressure on farmers to sell their produce immediately after harvest when prices are usually low. The Warehouse Receipt System Council, whose responsibility is to oversee the operations of the Warehouse Receipt System, was inaugurated in July 2020 vide the Warehouse Receipt System Act of 2019.

(iii) ***Traditional methods***

From a cultural perspective, different African communities have devised their own methods of post-harvest and on-farm storage to reduce food loss. Grains are stored in simple structures made from locally available materials such as bricks, straw and bamboo. Among the Mijikenda who live in the coastal part of Kenya, post-harvest preservation of maize is achieved by storing the grain along with neem (*Azadirachta indica*) leaves, which repels insects and prevents pathogens from attacking the grain. There are other traditional methods such as sun-drying of grain, use of bamboo bins and houses, silos, woven baskets, underground pits and gourds for storing food (Mobolade et al. 2019; Nwaigwe 2019).

5.5 *Packaging Technology*

Globally, the FAO has worked on several innovative technologies aimed at increasing efficiency of post-harvest handling and food processing. Open-source 3D printing technology is one of the innovations in which FAO offers online 3D designs of innovative equipment that can be downloaded for free. Within a period of less than two years, 13,000 downloads of a multipurpose wooden crate for transport, handling, storage and retail display of produce, have been made. As a result, much less food is lost along the value chain (FAO 2020b). The innovative design uses readily available wooden materials. This design is used widely in Sudan and Thailand. The FAO have also improved the output of smallholder farmers in Bangladesh by encouraging the use of crates rather than sacks to transport tomatoes. This has resulted in a significant reduction in the loss of tomatoes and an increase in their quality and shelf life (FAO 2020b).

5.6 Value Addition

A common occurrence in Kenya is over-supply of produce, creating a challenge in marketing and resulting in huge losses. Value addition technologies have been developed to reduce food loss at commercial and household levels. Capacity building is critical in the use of value addition technologies. The United Nations Women's organisation has trained 100 mango farmers in Kenya on the use of a multi-food processing machine for fruit processing, packaging and branding. The farmers, half of them women, are drawn from Meru, Makueni and Tana River Counties (UN Women 2021). The project, funded by the Rockefeller Foundation and other partners, involves institutions such as Jomo Kenyatta University of Agriculture and Technology (JKUAT), Stockholm Environment Institute (SEI) and Techno Serve. Another example of value addition is the training of 200 farmers to make jam from tomatoes in Malawi. The farmers are members of Zakudimba Producers Cooperative Society (ZAPCO) (Mahmoud 2018).

6 Conclusions and Recommendations

Sufficient evidence exists to show that significant food loss occurs at the farm level resulting from poor harvesting and post-harvest management practices. Furthermore, climatic changes, natural occurrences, human activity and slow implementation of policy, have contributed to food loss. The most significant impacts of food loss are hunger, malnutrition and reduced purchasing power, putting at risk the achievement of zero hunger and a sustainable food future in Kenya by 2030. Additionally, insufficient government funding for agriculture, and the inadequate capacity for value addition to reduce food loss, especially post-harvest, threaten achievement of a sustainable food future in Kenya. The literature reviewed shows that reduction of food loss through the use of enhanced technology improves producers' income and builds more resilient value chains, able to withstand climate-related shocks and stressors.

Reduction of food loss requires a multi-pronged approach in which policy makers, researchers and practitioners work together collaboratively on set goals and targets. To achieve these goals and targets, inputs to be considered include financial resources, providing people with requisite skills and knowledge, and systems for accountability along the value chain. The policy makers need to reassess and increase resource allocation for agriculture, and put in place mechanisms for intensified research by both government and non-government research institutions.

Intensified research should focus on exploring appropriate pre and post-harvest technologies to reduce food loss at all stages of the food value chain. Most importantly, a comprehensive analysis of the value chain will lead to identification of areas that require maximum input with regard to funds, areas of highest risk regarding food loss and development of innovative methods to reduce food loss. Research findings need to be appropriately packaged and disseminated to a wide audience using a variety of methods, for adoption and use by relevant stakeholders.

Adequate interaction and coordination between all actors as well as capacity building, are all necessary to provide a strong base for reduction of food loss. Capacity building on modern methods, on the use of indigenous technical knowledge, as well as on safe handling and preservation of food is a necessary component in food loss mitigation. Assessment of capacity building needs should take into account the situation in rural Kenya where men and women, boys and girls are all active participants in the food value chain. Attention should be given to the capacity building needs of women and girls, considering their unique participation at different stages of the value chain and the skills they need for making decisions on food and nutrition at the family level.

The impact of human activity relating to poor decision-making along the value chain can be addressed through three avenues: data collection, dissemination of the information and research to inform practice. At the dissemination level, appropriate channels for getting information to the various players in the value chain should be established. It is important to bear in mind that some of the farmers who most need to be reached are in inaccessible areas. With limited agricultural extension support around the country, these farmers are particularly susceptible to food loss, thus limiting the chances for realisation of the SDGs on hunger and poverty.

Accountability for systems and evaluation of processes and outputs along the value chain are critical for reducing food loss. A more conducive environment for sustainable partnerships would increase farmers' access to credit opportunities, capacity development and easy access to safe storage facilities. Private–public partnerships can help increase the sorts of investments that are important for the attainment of a food secure future for Kenya. These partnerships include enhancement of transportation infrastructure, expansion of rural electrification and financial support for national and county departments of agriculture. Also, important to consider is the development of rural financial markets to reduce post-harvest losses and provide broader socio-economic benefits. The suggested measures would contribute towards reduction of food loss, leading to the achievement of the Government's goal of zero hunger and a sustainable food future by 2030.

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Zimbabwe's Pfumvudza Agriculture Programme—Reality or Rhetoric?

Vincent Itai Tanyanyiwa, Tarisai Kanyepi, and Anyway Katanha

1 Introduction

An estimated two billion people globally are food insecure, and global projections indicate that the demand for food will increase to 70% by 2050, owing to climate change effects, urbanisation, population increase and change in diets. Therefore, meeting the (SDGs) and going beyond a "world with zero hunger" by 2030 calls for farm productivity to accelerate using innovative, cleaner processes and less water (FAO 2017). In Africa, the 2014 African Congress Declaration on Conservation Agriculture (CA) marked the scaling up of climate-smart agriculture (CSA) within agricultural structures in member countries to address food security and climate change.

Significant changes are already underway through the proposition of climate-smart agriculture in development agendas by policymakers and private players. However, the recent 2020 pledged Biennial Review (BR) Report revealed that only four countries, namely Rwanda, Morocco, Mali and Ghana, had surpassed the benchmark in meeting the Malabo targets on agriculture productivity. In Zimbabwe's agro-based economy, rain-fed agriculture predominates, plagued by drought and extreme floods events such as 2015/2016, El-Niño-related drought conditions and Cyclone Idai, in 2019 which have exacerbated the declining maize and wheat production trend

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over 2007–2016 (Chanza 2018). In response, the government adopted several promotional programmes varying from traditional initiatives such as *Zunde raMambo*, to the scientific Conservation Agriculture and the recent National Enhanced Crop Productivity Scheme (Command Agriculture). However, financial constraints and adverse effects of climate change have limited the scope of government's interventions (Cilliers 2020).

Contention and controversy remains centred over the assertion that CA increases crop yields in African smallholder farming systems despite adoption into agriculture policies, (Corbeels et al. 2020). Furthermore, despite the success rates of CA in South America, studies in Southern Africa, such as Corbeels et al. (2020) study showed that CA conserves soil by controlling soil degradation. The reliability of evidence claiming the success of crop yield benefits of CA, lag behind the narratives developed in Eastern and Southern Africa (Giller et al. 2009; Andersson and Giller 2012; Andersson and D'Souza 2014; Whitfield et al. 2015). However, the scaled uptake of CA still remains low, bringing into question its applicability in smallholder agriculture (Chiputwa et al. 2010).

The government introduced the Pfumvudza/Intwasa (local Shona and Ndebele names respectively) concept in 2020 as part of the government's version of CA as a response to the perennial food deficits and a climate-proofing approach. Pfumvudza was primarily aimed at marginal areas to improve yields and food security at a household level. Promotion of the Pfumvudza concept in the media reinforces the need for a nuanced and critical analysis of local implementation and farmer experiences to ascertain potential contradictory and complementary outcomes.

We approach the analysis of Pfumvudza in Muzarabani in Zimbabwe through the use of the actor-network theory (ANT), which attempts to unpack and challenge the assumptions and knowledge claim that underpin Pfumvudza's promotion and the human and non-human actor's interactions (Alberto and Oswald 2020). In semi-arid Muzarabani, a significant proportion of the marginal and remote areas suffer persistent food insecurity which begs the question, what does Pfumvudza concept mean in practice, and how can the actor network theory help unpack and understand Pfumvudza. The chapter first outlines the ANT conceptual framework, the Pfumvudza/Intwasa tenets and then Muzarabani economic, environmental, social scenarios.

While we do not attempt an exhaustive review of various localities of Pfumvudza implementation, we aim to complement existing reports on the potential benefits of Pfumvudza plots with farmers' perceptions. Against this background, the paper seeks to first identify the main costs and barriers to the adoption of Pfumvudza. Secondly, the paper attempts to identify possible entry points to harmonise policy provisions in addressing Pfumvudza. Thirdly the paper seeks to identify the components of a scalable framework that can ensure a robust rollout programme of Pfumvudza cognisant of varied agro-ecological contexts. While we do not attempt an exhaustive review of various localities of Pfumvudza implementation, we aim to complement existing reports on the potential benefits of Pfumvudza plots, including the voice of actors and beneficiaries pertinent in making tailored policy-relevant recommendations.

2 Conservation Agriculture as the Predecessor of Pfumvudza

Conservation agriculture (CA) is defined as an amalgamation of land management principles and an agriculture-focused technology characterized by zero or minimal-tillage, permanent organic soil cover, and crop rotations (Reicosky 2015). Growing calls for a reduction in emission from the change in land use and within the international climate policy discussions has seen the emergence of CA as a mitigatory farming solution. The international agriculture and development community widely advocated for CA due to the twin combination of good conventional practices and acceptable science to supply plentiful, sustainable, high-quality lifestyles to the world's populace.

As conservation agriculture grains traction in the future of agriculture discussions, many terms, namely synonyms ranging from regenerative agriculture, ecological organic agriculture in different global regions. Furthermore, varying approaches to the zero budget natural farming exists with CA practises such as organic manuring, crop rotation, cowl cropping and use of leguminous plants CA potentially contributes to stabilizing climatic conditions, balancing the hydrological cycle, and creating significant jobs in rural communities (Lovins et al. 2019; Brouwer et al. 2020). For example, for smallholder farmers, CA promotes productiveness without using synthetic fertilizers and sells the circular economic system of soils, re-establishing the symbiotic stability among healthy soils and animals. CA lets in the best allocation of sources and efficient use of waste, with the only drawback of the concept, being a behavioural factor (Mupangwa et al. 2017). The significant drawback of CA adoption is that the farmers quickly revert to their conventional methods once removing the "carrot", which is accessible free inputs (Edwards et al. 2013).

In Zimbabwe, CA is one of the broadest agriculture practises in the country, with high promotion among smallholder communal farmers, mainly in agro-ecological region IV and V infamous for their high temperatures and low rainfall conditions (GOZ 2015). Zimbabwe's Foundations for Farming and the internationally funded ConTilll program spearheaded CA adoption for smallholder farmers. Approximately 100,000 farmers smallholder farmers were involved in CA, placing 125,000 ha under production coupled with a free training and subsidized inputs as the main adoption driver. The agricultural extension services were implemented and funded by GTZ in the 1980s and 1990s. The agronomic trials of conservation tillage entailed experimental stations evaluating the weed pressure and soil erosion rates under varying tillage systems that informed the growing scholarship on reduced tillage benefits from Canada and Australia.

The disbursement of inputs to smallholders such as maize farmers, fertilizer and seeds rested on the condition that the recipients implementing CA became an established model in scaling it up. However, dependency syndrome emerged due to basis of free inputs offered and the maize-dominated agriculture status. In addition, sustained adoption of CA was largely limited by the lack of labour-saving technologies available for planting and weeding. Therefore, CA success remains a contested claim with only a subtle implicit acknowledgement in the literature of how they are inextricably politically influenced (Arslan et al. 2014; Ngombe et al. 2014).

3 What is Pfumvudza?

The proportion of food-insecure Zimbabweans surged by almost by estimatedly 50% to 8.6 million (or 60% of the population) by the end of 2020 due to the drought and economic recession (FAO 2017). The maize crop yield of season 2019/20 constituted less than half of the national requirement of maize staple cereal. The dire situation led to the government's introduction of Pfumvudza through the Government's Agriculture Recovery Plan, initially as an initiative to improve food security at household level. Furthermore, the concept aligns with National Development Strategy 1 (NDSI) and Vision 2030 vision of ensuring food security, eradicating hunger and poverty.

"Pfumvudza" or "Intwasa" concept refers to the blossoming of fresh leaves of Zimbabwe's spring, an indicator signalling the arrival of a season. Thus, in practice, Pfumvudza is a crop production intensification approach to ensure food security at the farm level using a small piece of land. Pfumvudza's based on three fundamental principles: minimal soil disturbance, minimal planting crops in small holes that trap rainwater and adopting crop rotation or inter-cropping for permanent soil cover using mulch, straw or other crops. Pfumvudza's uniqueness compared to CA is that it is asserted to produce more on a small plot measuring 39 m × 16 m (1/16th of a hectare) of land with fewer resources for a family of six's annual food needs. Crop production is through inputs and efficient labour use in a small area to optimise management through increased productivity. Pfumvudza gives hope to small-scale farmers with anticipation to bring higher yields per hectare, be environmentally sustainable, and provide a smart climate-proof way of ensuring food security.

Pfumvudza concept is based on the principles inherent of CA such as the minimal disturbance of soil, and adoption of crop rotation or intercropping practices using mulch, straws or crops. Pfumvudza's distinctness compared to CA is that it entails crop planting in small holes filled with trapped rainwater and is asserted to produce more on a small plot measuring 39 m × 16 m (1/16th of a hectare) of land. Furthermore, the basis is on fewer resources to meet the food needs of a six-member family household. However, in both concepts crop production is through inputs and efficient labour, thus concerns of timely implementation, efficient input usage and precision of operation are underlined in both concepts. Thus, from this perspective, the success of Pfumvudza, like CA, hinges on cognisance factors such as soil type (natural fertility and drainage), the type and application timing of inputs, rainfall type, which affects the flooding risk or drying of the pit area, and labour.

The government's knowledge dissemination through the media sources and provision of free inputs has increased awareness for Pfumvudzas adoption. The intensive promotion campaign included land preparation, private sector participation, door to door delivery of inputs and an estimated 5000 agriculture extension workers with new motorbikes. A study conducted by Mujere (2021), revealed that the concept increases yields per hectare, with higher potential to boost household food security resilience, yet the reduction of greenhouse emissions requires further analysis. However, other critics have critiqued the concept's on basis of owning a seemingly enhanced "evangelical tone" evidenced by sentimental expression of the practice promoted as "God's way" and the reference of the mulch and manure as 'God's blanket' (Scoones 2021) Thus, it is pertinent to include the voice of the farmers to assess the state of Pfumvudza preparedness.

4 Characteristics of a Pfumvudza Plot

The plot for Pfumvudza measures approximately sixteen meters by thirty-nine metres (16 m × 39 m) representing 0.06 ha or 624 m^2 (Mujere 2021). Three maize seeds are put systematically in every dug hole with 52 planting rows containing approximately 28 planting positions which maintain two maize plants post-germination stage after thinning. The spacing between rows is set at 75 cm (cm), and for inside the row spacing is set across the slope at is set across the 60 cm. (Mujere 2021).

The farmer needs to also dig pits set at 5 cm deep with addition of mulch, while seeds and fertiliser (Compound D and ammonium nitrate (AN) top dressing) the government provisions. The expected yield output of estimated 56 maize cobs from each row, which entails that a total amount of 20 kg of shelled kernels is produced. Thus, with the asserted calculations, 52 plant rows constitute 52 grain buckets that can meet the food requirements of a family of six for a year. A typical outline of a schematic layout of a Pfumvudza plot showing its measurements is illustrated in Fig. 1.

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The programme lays out plans for three different types of plots namely, the two plots assigned for grains as the staple food namely maize and sorghum. The third plot is assigned for small grains such as soya beans, cowpeas, sunflower that can be grown on a commercial basis (Mujere 2021). Under Pfumvudza, the second plot,

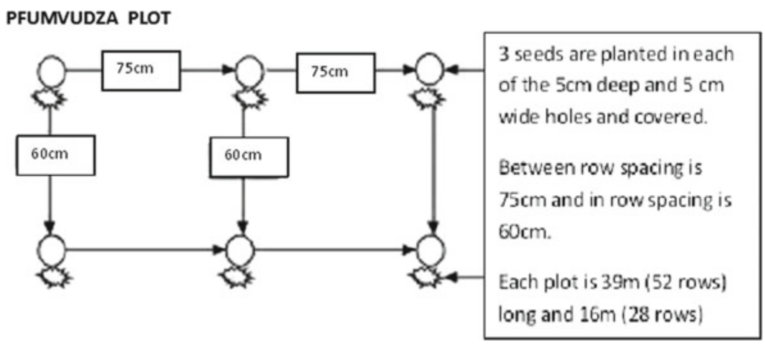

Fig. 1 Pfumvudza plot. *Source* Authors

under small grains such as cowpeas or groundnuts is mainly for two motives. First, since the main plot is only for domestic food intake, the soya bean plot profits for relatives' circles; second, the use of soya bean to rotate with maize every year lets the maize plant benefit from the nitrogen-fixation from groundnuts.

5 The Actor-Network Theory (ANT)

There is a paucity of studies from natural resource management discourse using ANT to analyze policy or farmers' agricultural knowledge (Schneider et al. 2010). The actor-network theory defines the relational ties made and remade between human and non-human entities within a network or assemblage. The ANT has been adopted in unpacking scientific and/or technological innovations and identifies the human and non-human actors and how they network (Schneider et al. 2010). These human and non-human entities in a network are termed actants which are also assemblages within themselves. The actors in a network can include collectivities of human beings (policies, organizations, companies and tools), it could cover non-people (animals, machines, plant life, files), and intangibles (institutions, ideas) (Oña-Serrano and Viteri-Salazar 2020).

The ANT theory was appropriate in examining the Pfumvudza concept to understand how the Pfumvudza network's human and non-human actants interact, their roles and how they participate in the process through components, such as a farmers and decision-making structures engaged in the project. The theory was selected as it enabled the players in Muzarabani adoption of Pfumvudza and the integral vitality of the community's food system and its functioning parts. Also, it valuable in the identification of the human and non-human actants constituting the network and needs of the farmers and decision-making structures engaged in the project. The ANT also helped to explain the relationships between nature, technology and society (Schneider et al. 2010). However, the theory is criticized for its tendency to be boundless in describing components and negating external social forces like culture, gender, power relations, scale, race and religion.

The ANT is appropriate for this study as it validates the equal partnership of living and non-living entities in a network. Cressman (2009) discusses how "human actors" give meaning through their relationship with other parts of the broader network. The particular belief of viewing non-living parts as more than resources to be used sheds light on the tendency to overlook the intricate relationships between "human cultures and other forms of life and inorganic materials" as essential for human interactions. The ANT-based method ascertains how Pfumvudza plot farming affects information creation and power associations. The Pfumvudza plot has various actors who need follow-up data to engage in inventive approaches and form a web of support. While past research acknowledges networks importance, there is insufficient exploration of networks' role in Pfumvudza farming. The ANT explores Pfumvudza in practice to unravel plot management networks through a continuous process.

6 Methodology

The ANT is appropriate for studying innovations because of its attention to unpredictable ends. The ANT focuses on the development process through the creation of heterogeneous actors' associations. The relationship between 'natural entities and social actors,' devices and technologies is based on " symmetry" principle by placing human and non-human actors equal in analytical priority (Arora and Glover 2017). The ANT has been applied in the environment, agriculture, and society based on innovation, knowledge and a non-linear and interactive process in transforming the actors during translations (Latour 2005; Jarosz 2000).

The theory was adopted due to its strengths in describing networks, the actants whether human or non-human and how they come into or out being and their contingencies. The ANT is appropriate for this study as it validates the equal partnership of living and non-living entities in a network. Cressman (2009) discusses how "human actors" give meaning through their relationship with other parts of the broader network. The particular belief of viewing non-living parts as more than resources to be used sheds light on the tendency to overlook the intricate relationships between "human cultures and other forms of life and inorganic materials" as necessary as human interactions. The ANT-based method ascertains how Pfumvudza plot farming affects information creation and power associations. The Pfumvudza plot has various actors who need follow-up data to engage in inventive approaches and form a web of support. While past research acknowledges networks importance, there is insufficient exploration of networks' role in Pfumvudza farming. The ANT explores Pfumvudza in practice to unravel plots management networks through a continuous process.

The literature review search focused on the generic search terms "conservation agriculture", "Pfumvudza", using Web of Science and Google Scholar with a focus on assessing the state of Pfumvudza. The screening of abstracts for relevance to the Zimbabwean context was ordered chronologically and checked to identify any coincidence of new narratives. Farmers' perceptions were critical in judging Pfumvudza, thus twenty-six semi-structured interviews with actors in Muzarabani, namely the residents, Pfumvudza plots organisers, actors from non-profit organisations and government agencies, such as the AGRITEX officers. Furthermore, data collection was also done through non-participant observation at six selected Pfumvudza plots and community meetings.

Interview Questions
1. Meaning of Pfumvudza
2. Actors and development procedures of Pfumvudza plots
3. Pfumvudza plots challenges and solutions
4. Actors, institutional structures, and decision-making
5. Pfumvudza's contribution to food security and livelihood

7 Muzarabani—A Brief

Muzarabani, a district in northern Zimbabwe location extends from 30° 45″ E to 31° 20″ E and 16° 00″ S to 16° 30″ S. Muzarabani is located in Mashonaland Central Province, one of the ten geopolitical province in Zimbabwe It is located 300 kms from Harare.

Located in a flood-prone region owing to the proximity to the adjacent to the flood plains of the Zambezi River, upstream Lake Kariba and downstream Lake Cabora Bassa at the confluence of the Musengezi and Zambezi rivers about 400 m above sea level (masl). The district has 22 wards with four chiefs; Changara, Chiweshe, Hwata, Kasekete, and sub-chief Muzarabani of predominantly *Vakorekore* clan and *Vavhitori* and *Vazezuru* as a minority. Muzarabani is 4266 km^2 in extent and a density of 28.78/km^2, a population of 122,791; 49.8% males numbering about 61,160 (ZIMSTAT 2012). Muzarabani has fertile soils along the flood plains supporting crop production and a dense population. A dense population density is due to fertile soils along the flood plains that support crop production. The area has chromic luvisols, sandy textured; which are wind and fluvial erosion-prone (Manyani 2013) (Fig. 2).

Muzarabani is located in agro-ecological region 4 that receives annual rainfall ranging between 450 and 850 mm per year during the months of December to March. Rainfall is higher on the escarpments and plateau, averaging 1000 mm per year, and falls during a more extended wet season from November to mid-March. A long dry season is common from April to October (Fergusson et al. 1992). Temperatures range around 35 °C in November and 14 °C in June. Normal rains start in October–December. Frequent seasonal droughts and severe dry spells appear during the rainy season (Moyo 2000). Agro-ecological region four is suitable for extensive production systems, forestry, livestock production, tourism and wildlife (Vincent and

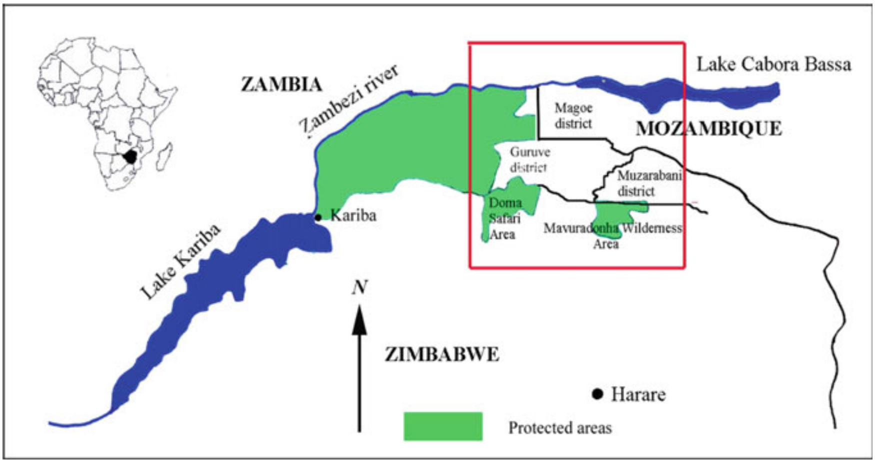

Fig. 2 Location of Muzarabani in Zimbabwe. *Source* Adapted and modified from Cunliffe, 1992

Thomas 1961). Muzarabani is predominantly agro-based, although it is affected by adverse environmental conditions, drought, flooding, high temperatures, and related epidemics. Muzarabani has indigenous trees such as Acacia Nilotica (Mimosoideae) [local name, Muunga], Adansonia digitata, Colophospermum mopane (local name, Mopani), Diospyros mespiliformis, Strychnos innocua and Ziziphus mauritiana.

Muzarabani has three discrete geographical regions: a broken mountainous plateau in the south (800–1300 mm), the Zambezi Valley to the north (350–500 mm) and an escarpment of mountains that spread from the east to the west. Droughts are a perennial challenge, although floods rise to unprecedented levels in some years. Flooding is due to the increased flow on the Hoya and Nzou-Mvunda rivers, and a backflow from Cabora Bassa and inflows from the Zambezi River Flooding is also due to the release of water between December and February from the Kariba Dam to avoid dam failure that result in substantial discharge into the Zambezi River.

Discharge into the Zambezi results in Cabora Bassa Dam level rise due to inflows from Kariba Dam and Zambezi River feeder tributaries. The resultant backflow cause floods, animal, human and vegetation losses. Land use in Muzarabani includes subsistence agriculture through growing drought-tolerant cotton, finger millet, maize, pearl millet and sorghum. Goats, cattle and guinea fowls are the common livestock. Furthermore, there are wildlife habitats, with ecotourism on the Mavuradonha Wilderness Area and utilisation schemes in the Zambezi valley alongside small-scale commercial agriculture or large-scale commercial agriculture on the southern Zambezi escarpment. In 2018, an Australian firm, Invictus Energy, found an oil field and gas in northern Muzarabani.

8 Results and Discussion

8.1 Pfumvudza Networks

Taking a Pfumvudza plot as an actor-network, many elements/actors are translated and enrolled in farming. The actors, basing on the heterogeneous nature of Pfumvudza concept, include the hoes, manure, wheelbarrows, the fields, sunshine, rain, own family labour, knowledge and the interactions within the actor-network approach illustrated in Fig. 3. Pfumvudza approach from an ANT technique is that actors are engaged to get their positions and activities through the relation placements (Law 1999; Lequin 2021). A particular Pfumvudza plot will get manure/grass/tree leaves from the other nearby farm and fertilizer.

The Pfumvudza concept raises many questions because of the complex systems that develop due to the interactive nature of different actors in Fig. 3. A Pfumvudza plot can produce 4 tonnes of maize and up to 5–6 tonnes in another season. The heterogeneous community of actors are not all limited to physical site of Pfumvudza plot. Rather, there exist a mass of actants namely seeds, manure which are limited to the

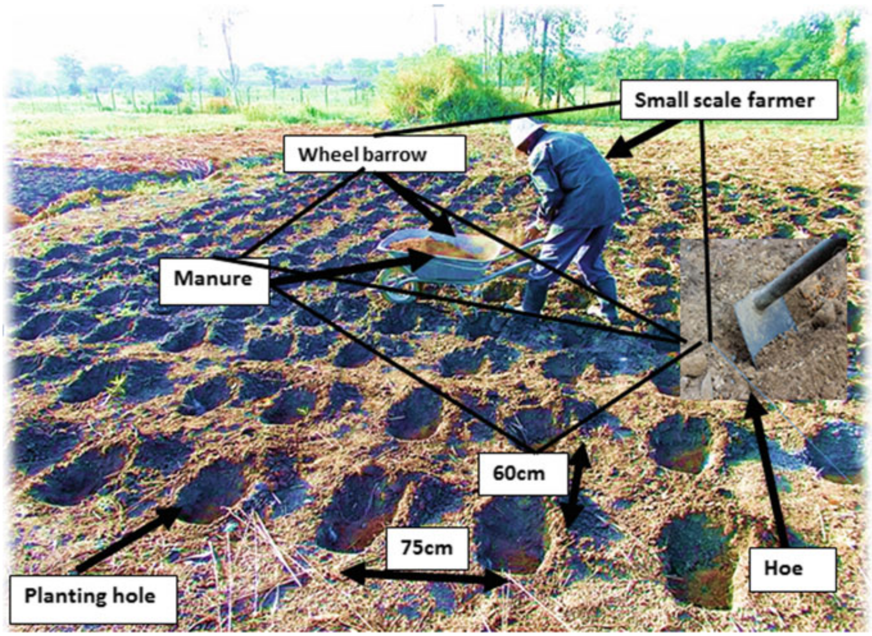

Fig. 3 Pfumvudza human and non-human actors networking. *Source* Authors

Pfumvudza plot and then external actants not limited to physical plot but include agriculture extension officers, advisors, magazines, climate forecast, labour and subsidies beyond fertilizer subsidy availed by the government. For example, the Econet Wireless' Eco farmer which provides services ranging from weather information, insurance to general farming advice through the Eco Farmer programme, In addition, the non-human actors in Pfumvudza are culture, land preparation, planting, weeding, harvesting, and marketing and advertising which play more or less a supportive position (Mujere 2021; Manyani and Bob 2017).

The Pfumvudza plot organisation from an ANT approach, and the relational of entities are enrolled to get their forms and performances through the family members. Muzarabani farmers adopt the Pfumvudza because their agricultural plots are small, although with extensive labour. The human and non-human actors, the hoe, manure, deep holes, knowledge, man, women and children are readily available. The Pfumvudza is introducing commercial agriculture in Muzarabani as farmers strive to produce surplus food and earn cash, that is, 49% of their cash earnings via plot-farming sports. Although Pfumvudza plots are for subsistence-low manufacturing structures, different green commercial companies via growing high-fee plants and animal husbandry boost income.

In the case of Muzarabani, the varying steps in accessing resources affect's the network's ability to minimise the effects of droughts of flood to farming. For example, the issue of adequacy of assessment to determine the appropriateness of seed type availed depending on the area's agro-ecological conditions or soil type was a limiting challenge. Critical for understanding the Pfumvudza concept as a paradigm shift is appreciating the idea based on power, particularly from an African perspective, regarding the power dynamics and political influences that may appear in food security discourses. Thus, the influence of power dynamics cannot be overlooked regarding the Pfumvudza experience.

For example, the limited access to monetary and physical assets has an extreme effect on the network's coping approach because it limits access to loans from banks. In the case of Pfumvudza, the government partnered with the private sector, including SeedCo and Mukushi Seeds, to implement the Pfumvudza concept nationally. Although there was "a crop and livestock assessment exercise to come up with yields (metric tonnes per hectare) and production (tonnes) countrywide, there has been complaints of inadequate assessment of soil type, timely implementation and power dynamics through favouritisms and adequacy of seed or fertiliser quantity availed."

Cases where different seed types had varying results owing to failure to adequately consider soil type were also noted in studies from Wondedzo where owing to sandy soils leaching was more pronounced (Scoones 2021) While in Gutu Chatsworth, the Syngenta seed availed in the programme performed poorly as compared to the SC513 seed type locally bought by farmers.

Farmers expressed that they had actively followed the uptake of the programme, yet they bemoaned delayed incidences of varying timing of delivery of inputs, concern over the quantity of fertiliser availed and minimal cases of corruption or favouritism in accessing the inputs.

Although the country's agricultural extension system suffers due to high extension agent to farmer ratios and mobility challenges, the availing of 5000 agriculture extension officers and new motorbikes was a step in the right direction towards the launch of Pfumvudza. However, availability of personnel to cover the entire region in Muzarabani, presented challenges limiting farmers' grasp of the basic Pfumvudza tenets.

It is crucial to note that other human actors such as Faith-based organisations like the Foundations for Farming, the Zimbabwe Council of Churches and the River of Life Church already engaged in Climate Smart Agriculture practices, particularly conservation agriculture, were another vital factor in training and establishment of Pfumvudza plot demonstrations. In addition, actors such as the Food and Agriculture Organization of the United Nations (FAO) also assisted and the Foundations for Farming (FF) in educating and empowering government extension staff to enforce the Pfumvudza concept, containing CA practices.

Thus, if a Pfumvudza plot must produce 6 tonnes of maize, the maize crop might get affected by locusts or drought or otherwise not satisfy the expected output. A selected Pfumvudza plot uses grass and tree leaves as manure from the field and nearby farms. Theoretically, the equal manure produced may produce more than a tonne of maize and over 5 tonnes in another depending on the external entities that are enrolled and mobilised as actants into the farming strategies, namely seeds, fertilizer, advisors, capital, magazines, climate forecasts, fodder, food chains, colleagues, knowledge, labour and subsidies. There is a need to explore differences for the opposite entities enrolled, including the type of hoes, amount of labour and knowledge systems.

8.2 Socio-Economic Benefits of Pfumvudza

In Muzarabani, despite the various attractive facets to the Pfumvudza production paradigm, the ever-increasing population brings into question the potential of Pfumvudza to achieve food security and sustainable goals as land constraints exist.

The scalability of the Pfumvudza plot initiative has been a primary factor in its relative successful adoption in Muzarabani as the farmers noted that it reduces workload due to the limited plot size. Vulnerable poor households often rest on Pfumvudza plots for their staple food and secondary supplements.

Pfumvudza is not all about growing maize as often suggested. In Muzarabani, Pfumvudza plot gardeners are engaged in vegetable growing, and some specialise in watermelons. Pfumvudza plot farming's key benefits include but are not limited to improved and increased nutritious food and meal diversity. However, a lack of collateral protection required by banks to get seeds and other inputs and inadequate training have always been limiting factors for the farmers in the area.

The three Pfumvudza plots focuses on the staple crop and small grain for commercial purposes ensures that food security at household level and a source of income. All this lowers production costs because natural fertilisers are extensively used. The Pfumvudza plot farming concept warrants meagre labour expenses because of family labour. Drought and erratic rain compel families to use water buckets as irrigation options. The cost of non-labour inputs is US$50 for hybrid seeds. With low cost, accessible natural fertilizers, the non-labour cost value decreases to zero dollars.

Beneficiaries of the government's Presidential Inputs Scheme and the private sector Mukushi Seeds company have been able to plant varied maize and vegetables such as sweet potatoes, beans and sunflower. However, some resource-poor families' have constraints in admission to production inputs have refuted the claim that Pfumvudza is less costly and calls for fewer inputs and investments. Crop and cattle production in Pfumvudza plots can generate many sales in keeping with the unit area as Muzarabani is a crop production region (Plaza-Bonilla et al. 2015). Farm animals and gardens diversify hazards and risks because crop losses provide a buffer and an asset to the family.

Multiple social benefits of Pfumvudza plots include: enhancing food and dietary security, socio-economic and political stability, enhancing own family health and human capability, empowering women/girls, social justice and equity, and preserving indigenous knowledge systems and sub-culture (Mupangwa et al. 2017). The maximum essential social benefit of the Pfumvudza plot in Muzarabani stems from their direct contributions to the family food safety net through growing, availability, accessibility, and food products usage. Pfumvudza plots are found near homesteads, ensuring easy access to fresh plant and animal food. Food items from Pfumvudza plots add meaningfully to the family strengths and nutritional requirements (Fig. 4).

The Pfumvudza is the entry point for smallholder farmer food security in maize and other crops such as soya beans. These two crops provide feeds for a small chicken unit with a potential to generate income and long-term nutrition (Edwards et al. 2013). Pfumvudza is thus ideal for climate proofing agriculture and poverty among peasant farmers. Pfumvudza is criticised as mechanistic and lacking adequate practical relevance (Mujere 2021). The issue could be due to seed appropriateness for Muzarabani. There is a need for further assessment of the seed appropriateness since this is a flood-prone region. In dry regions, such as Matobo and Mwenezi, the Pioneer and SeedCo varieties that were availed by government resulted in bumper harvest although maize varieties differ in grain yields per cob. Pfumvudza is however perceived too imaginary with idealistic expectations (Mujere 2021).

Pfumvudza plots afford monetary and food safety benefits to farmers in Muzarabani who are periodically affected by floods and drought. Recent studies show that Pfumvudza plots contribute to income, advanced livelihoods, and family financial welfare, in addition to increasing entrepreneurship, technopreneurship, and rural improvement (Mzyece 2021). Through the evaluation of several cases research confirms that Pfumvudza plots can contribute to family finances (Thierfelder et al. 2013; Phiri et al. 2019); farming sports may evolve into a small cottage enterprise, and income from the sale of home lawn products and the savings from eating home-grown meals. Studies from Nepal, Cambodia, and Papua New Guinea chronicle that the income generated from the sale of the home lawn, vegetables, and farm animals

Fig. 4 Promising Maize yields in Muzarabani March 2021. *Source* Authors

merchandise allowed households to use the proceeds to purchase extra meals, gadgets and financial savings (Rodenburg et al. 2020).

The Pfumvudza concept is criticised for its simplistic assumption that the crops will reach maturity and harvest without losses due to pests and diseases. The consumption of green produce, such as green mealies reduces harvests (Mujere 2021). In Muzarabani, climate change leads to yields decline. Farmers acknowledged the strengthening of agricultural production by using locally available inputs and technology; this entails realising that all actors are essential in any Pfumvudza process. Pfumvudza depends on extreme externalities, especially the physical environment, which potentially does well for the rich.

A Pfumvudza plot consists of a ramification of additives and species representing social and conventional components of different societies. This rich indigenous way of life and communal information base is through domestic plot farming using vegetation and animal species and the local community's practices. Pfumvudza plots produce sales that improve the circle of relatives' financial popularity, providing extra earnings and contributing social and cultural enhancement (Manyani and Bob 2017). Pfumvudza plots serve as a precious repository for retaining and transferring indigenous crops and farm animal's species and production expertise. Relations in and around the house plots strengthen social repute and ties between the family and the network. A Pfumvudza plot habitually alternate or present planting materials, greens, culmination, leaves, herbals and medicinal vegetation for social, cultural, and spiritual purposes. Such interactions involving farmers are essential for social integration and building social capital.

9 Uplifting the Status of Women in the Pfumvudza Programme

Women in various societal positions play a vital part in food production, with their worth surprisingly undermined (de Paula et al. 2021). Women are active in CA or Pfumvudza plots farming, even though their contribution within the local plot garden determination is not realised by socio-cultural norms (Hove and Gweme 2018). Despite the Pfumvudza gardens contribution to households' needs waning, women had their earnings and social reputation enhanced (Mujere 2021). Women's roles and responsibilities in Pfumvudza plot farming vary. Through Pfumvudza gardens, women have interacted with their environment and developed talents associated with plants and animal administration to become environmental managers.

As home managers, women have beneficial knowledge of several home needs, and their involvement in crop production meets their family desires (Hove and Gweme 2018). Home farming sports are vital and inform women's everyday home sports and employment styles alongside their cultural and aesthetic values (Sithole et al. 2016; Mujere 2021; Andrijevic et al. 2020). Muzarabani has women network who can run successful Pfumvudza gardens and are thus important actors e.g. local shops, the Zaka women of Zimbabwe, Pfumvudza farming helps uplift a woman's social prominence and determines her dedication to their own family's health and welfare (Hove and Gweme 2018). In Ethiopia, women through CA projects, contribute immensely to the family's food security and health concerns (Maru et al. 2017). Women gardeners in Muzarabani are willing to provide meals in the vital circle of relative's intake as although male gardeners are conscious of excessive advertising charges. While Pfumvudza plots provide a direction for women to contribute to family subsistence, eminence, and personhood, they preserve farming knowledge and records (Westengen et al. 2018).

10 Environmental Benefits of Pfumvudza

Pfumvudza plots provide a couple of environmental and ecological advantages. They feature the primary unit that initiate and use ecologically unique food safety net approaches whilst preserving biodiversity and natural assets. Pfumvudza plots are typically numerous and comprise a rich composition of plant and animal actors/species. Hence, they make enjoyable instances for ethnobotanical studies (Sithole et al. 2016). The use of artificial fertilizers for Pfumvudza plots defeats the whole agro-ecological principle as enshrined in climate-smart agriculture, and some experts highlighted that it is not a sustainable way of soil improvement since it weakens and pollutes the environment.

Muzarabani chromic luvisols are sandy textured; they are wind and fluvial erosion-prone (Manyani 2013). Sandy soils leach, and in some areas with heavy soils, water-logging was reported. Muzangwa et al. (2019) suggest upgrading soil quality in semi-arid environments after residue retention and legume farming in maize-based no-till. However, such improvement is a long-term process (Sithole et al. 2019). Pfumvudza gardens constitute a sizeable consciousness of plant life used as greens, fruits, herbs, drug treatments, yams, and spices.

An extensive spectrum of plants, birds and insects are actors in the websites for in situ conservation of biodiversity and genetic material (Rodenburg et al. 2020). Pfumvudza plots also provide some ecological services which integrate actors such as habitats for birds, animals and different beneficial organisms, nutrient recycling, decreased soil erosion, and better pollination (Muzangwa et al. 2019). Due to the enriched soil environment, Pfumvudza plots have a high density of vegetation that render shelter for flora and fauna. Hove and Gweme (2018) highlight several ecosystems offerings supplied using CA Pfumvudza plots together with the manufacturing of high-quality food, preservation of landraces, cultural services, pest control, and pollination. Ecosystems services provided via CA Pfumvudza plots range from small-scale to commercial agriculture (Mupangwa et al. 2017; Thierfelder et al. 2016; Penot et al. 2018). Another ecological gain of Pfumvudza plots is nutrient regeneration. Diverse actors facilitate green nutrient cycling. Pfumvudza plots discount soil erosion and land conservation (Muchuru and Nhamo 2019).

The appeal of honey bees brought benefits together with improved pollination and accelerated fruit dispersal. Family entities, animals, and plants all preserve an interdependent courting in the Pfumvudza plots, for example, plant life, insects and animals offer relish, meat, and other goods for the family subsistence Plant materials are animal fodder; animal manure are integrated into the compost to fertilize the soil thus reducing chemical fertilizer use. Livestock and chicken manure add a considerable amount of natural soil count, nitrogen, potassium, and phosphorus. Integrating farm animals' sports into Pfumvudza plot farming can expedite nutrient cycling in the environment and help conserve moisture.

11 Barriers to the Adoption of Pfumvudza

The motives for Pfumvudza's slow adoption is due to increased labour due to the higher proportion of the older population in the rural area of Muzarabani and the disdain towards farming by the youths. Youths consider the low profits and tenuous nature of farming without adequate inputs and infrastructure. Maize is a typical the low profit crops in comparison to oil crops such as groundnuts and gold-panning in Muzarabani. Ownership is another barrier to ensuring sustainability in the Pfumvudza model, particularly in African farming where the man owns the land.

Among numerous constraints, access to appropriate and adequate land to set up a home garden is a challenge, the loss of ownership of land for women due to widowhood and their exclusion in land rights due to patrilineal cultural norms remain. These factors are restrictive f since not everyone has a piece of land in Muzarabani (Chanza 2018). Furthermore, beyond absence of land tenure, lack of collateral to secure loans or insurance increase vulnerability to climate extremes such as flooding and drought. Thus, as climate variability and change accelerate, there is a reluctance by the private sector to finance smallholder farming. Farmers have no buffer to increase production or guarantee food security without agriculture financing.

Lack of linkages to other actors such as inputs, extension and advisory services, and market entry are insurmountable challenges. The cultural and political reputation of Pfumvudza is a constraint because Pfumvudza's link to the ruling party (Zanu Pf) which has responsible for creating inconsistencies in access to Pfumvudza inputs and resources. Other limitations include a poor human resource base, limited knowledge and credit and climate finance challenges, increasing and sustaining Pfumvudza measures' adoption. Generally, smallholder farmers follow unsustainable conventional tillage that cause environmental harm. Unsustainable water management practices are common including, tree felling, and flood irrigation especially in water-stressed areas. These challenges further increases defoliation, forest degradation and soil infertility due to low soil moisture content. Muzarabani small holder farmers have limitations in terms of adequate institutional and technological capacity to maximize germplasm of crop and livestock as well as the absence of climate change mitigation and adaptation education and information. Furthermore, there are no, agriculture training colleges, universities and extension services training in the area. Livestock husbandry depends on open grazing that leads to land degradation, and forest cover loss. The result is greenhouse gases emissions into the atmosphere, thus buttressing that livestock farming is a significant global methane emissions source.

There is a gap in the documentation of indigenous soil and water conservation techniques, information and experiences documented on alternative techniques that can improve Pfumvudza practices through research. Gender inequality is a limitation; women cannot easily champion agricultural production and productivity due land tenure and ownership. Tenure constraints, access to inputs, resources and credit, education, and extension services are more challenges. Female-headed households are disadvantaged in terms of labour provisioning. Climate change's effects threaten to intensify inequalities. Over reliance on natural resources for food and income is problematic under climate change. Men and women have differences in vulnerabilities and hence their needs in terms of Pfumvudza adoption and implementation differ.

In Zimbabwe, women generally have low educational attainment. Poverty exacerbates women's marginalization and vulnerability, hence their immediate buy in of Pfumvudza is slow. Agricultural technologies and practices are not gender-neutral, as in Pfumvudza, including its adoption and scaling up. Women have low adoption of Pfumvudza because they have insecure land tenure, lack capital, limited access to climate information, limited assets, few farm inputs, limited mobility, restricted decision-making power, and inadequate extension services. Early warning systems and agro-advisories fail to give women localised disaster risks and inappropriate information dissemination, especially in Muzarabani marginal location.

The challenge is for would-be advisers to develop a sense of partnership with farmers, participating in defining and solving problems rather than only expecting them to implement projects prepared from outside (FAO 2005). Instead of using a top-down approach where the extension agent places Pfumvudza demonstrations in farmer fields and expects the farmer to adopt, a more participatory system is required where the farmers are enabled through the provision of equipment and training to experiment with the technology and find out for themselves whether Pfumvudza is sustainable and what fine-tuning is needed.

12 Conclusion and Recommendations/Policy Implications

12.1 Conclusion

There is a recognition that organising sustainable food structures via scaling-up Pfumvudza relies upon the interdependencies of context-specific socio-economic and environmental factors. In Muzarabani, this entails the system's adaptation, including the building of cross furrows and other drainage systems, particularly where the Pfumvudza plots fared worse off than the conventional farming areas. Any agronomic system must adapt to different conditions, as there is no such thing as a normal year.

Mixing different approaches within a farm may be an important way forward, rather than seeing Pfumvudza as 'the solution'. The ANT's assessment of the Pfumvudza concept reveals a broader understanding of the connection between human and non-human actors. Pfumvudza plots are an eco-friendly sustainable agricultural practice to improve, protect and beautify the landscape. There is increased adoption of Pfumvudza due to its supposed benefits. Pfumvudza is labour intensive and therefore, may appeal to the young and the elderly. The form, features, and contributions of Pfumvudza plots range in farming regions in the country. In the wake of a global food disaster and the high food prices, there is extended emphasis on improving food structures with renewed attention to food production and livelihood enhancement. The entry point for a fully-fledged Pfumvudza programme exists because earlier indigenous farming methods are similar to Pfumvudza. However, there is a need for value recognition of the earlier technologies that can be an entry point in Pfumvudza policy formulation. Pfumvudza solutions should not be prescriptive but relatively flexible and consider developing more location-tailored digital and farming advisory needed by smallholder farmers that consider the low agriculture extension to farmer ratio. The collaboration between the Meteorological Services Department (MSD) and the Agricultural Technical Extension Services (AGRITEX) and Telecommunication providers should prioritize information dissemination tailored climate advisory and crop-specific information at the grassroots level.

12.2 Recommendations/Policy Implications

There is a need to identify and scale a gender-sensitive lens to Pfumvudza solutions that prioritize investment and sustainable financial instruments structures such as green bonds and blended financing. Increased youth engagement and technology access and use should be prioritised to promote agri-business entrepreneurial solutions aimed at the Pfumvudza programme beyond the input or production stages of the agro-food value chain. These strategies may go a long way in ensuring livelihoods improvement and poverty. Need for Tailored weather and climate advisory updates for farmers that should consider farming processes where climate and farming information is disseminated through simple platforms such as radio and mobile phone. The government should establish market linkages for farming communities such as engaging the private sector for Pfumvudza-related finance and crop- contract schemes for legumes or drought-tolerant crops such as millet for local and international markets. The development, tracking and monitoring of policy implementation and support services to women should address the intensification of biased pre-existing inequalities that exclude women in rural areas in decision-making and resource access. CA is the future, but requires a coordinated approach that is apolitical. Reconciling these extremes and locating the proper stability should be the mission of the current generation. The entities and actors who can be enrolled or no longer enrolled in the community and how they are enrolled is characteristic of the agency. The agency is on whether the industrial specialists or farmers' unions enrol and what performances they have enrolled in the Pfumvudza value chain. Raising awareness should be enhanced to expose men to the challenges of socially constructed norms such as accessing finance and support services. Farmers, who have not started Pfumvudza are encouraged to begin holing out and mulch. Soil sampling and analysis should guide the input type and appropriate farming techniques to tailor and improvise Pfumvudza implementation. The Pfumvudza Programme, like all other agricultural programmes, needs well trained and capacitated extension officers for technical training, tracking and monitoring.

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Livelihood Diversification and Household Food Security in Selected Agrarian Settings of Western Zimbabwe

Douglas Nyathi and Joram Ndlovu

1 Introduction

Over the years there has been an increase in the diversification of smallholder farming due to its potential to contribute to increased food security in remote areas (Koppmair et al. 2017; Ecker 2018). Rural households have become vulnerable due to climate change resulting in malnutrition and other social ills (Grote 2014; FAO et al. 2014). Though food security is a problem of global proportions, it's devastating impacts are experienced differently. Weather related problems have become more severe in Sub-Saharan Africa. Rural livelihoods diversification increases sources of income and by extension expands markets for agrarian produce and promotes households' food security (Ellis 2000; Nyathi et al. 2018). The burgeoning anecdotal evidence shows that emphasis should be placed on livelihood portfolios in order to understand rural farm households' food security (Mzuyand 2020). Thus, there is a close relationship between livelihood strategies and food security. From a sustainable livelihood perspective, food insecurity has been deepening in recent years especially in the Global South with sub-Saharan Africa being the worst affected (Ellis and Freeman 2005). Due to food insecurity, people in Sub-Saharan Africa, people's health, productivity as well as their survival is affected severely. Since most of people depend on rain fed agriculture, there are likely to remain food insecure as a result of climate change (FAO et al. 2014). Although there have been notable strides made towards ensuring global food security, food security still eludes most people in semi-arid regions.

Therefore, flooding, heatwaves, droughts and political conflicts have resulted in food crises in sub-Saharan Africa. Consequently, different regions have been negatively affected due to decreased food production levels (He et al. 2019). We hypothesize as follows: H_1: In sustaining their living, rural communities that are well-off

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engage in few activities with higher returns compared to poorer households who engage numerous low-value activities. H_2: Extremely dry episodes are positively associated with the push factors to diversify livelihoods for people in the western part of the Country. H_3: The motive to diversify livelihoods beyond agriculture is used by households as an effective way to get alternative sources of income in order to cope with adverse environmental impacts.

2 Methods and Study Location

The study used a multisite case study design. Data was collected form three sites namely, Springrange farm, Fox farm and Rockdale farm. The sites are located in the following districts; Umguza, Bubi and Matobo. Umguza and Bubi are located in Matabeleland North whilst Matobo is situated in Matabeleland South. The map below shows the Matabeleland South and North districts. See Fig. 1.

Matabeleland North and South Provinces are vulnerable to erratic climate conditions resulting in poor rain fall and water shortages. Poor soil fertility exacerbates the problem resulting in low crop harvest (Nyathi et al. 2018; Assan 2014; Bird et al. 2002; Ellis 2000; Hussein and Nelson 1998). Fox farm located in Matobo district in Matabeleland South receives less than 450 mm of rainfall per year. Rockdale and Springrange farms which are situated in Matabeleland North receive an average of

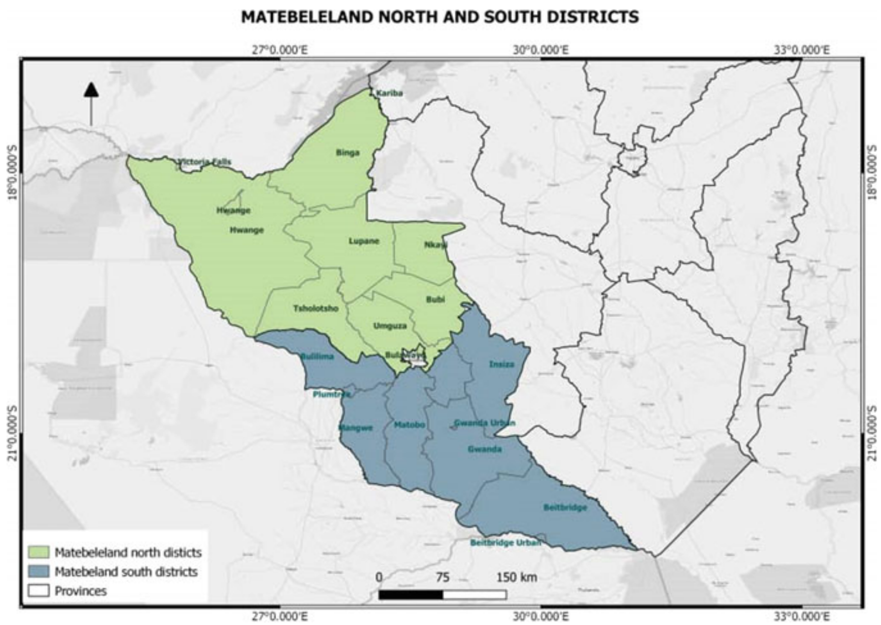

Fig. 1 Matabeleland North and South Districts

450 and 600 mm annually. There are different livelihood strategies used in the three selected farms. Most farmers in Umguza district survive on subsistence farming by growing small grains and maize (Thebe 2011). Other livelihood portfolios include livestock such as cattle, sheep and goats. Similarly, Matobo farmers thrive on small grain production and major in cattle rearing. In order to sustain their living, communities in the Matobo district rely on informal trade, collection of wild fruits, and harvesting of mopane worms as their main sources of their livelihoods (Nyathi et al. 2018; Assan 2014; Bird et al. 2002; Hussein and Nelson 1998). In order to sustain their livelihoods, households in the three selected farms rely on remittances from different countries such as South Africa Botswana, and Europe (Maphosa 2009).

To understand livelihood diversification in the three selected farms, an interpretivist paradigm was used to understand the social reality of rural house households. Through the use of language and shared meaning, interpretivists believe that people's perceptions of what is real is socially constructed (Denzin and Lincoln 2011). Interpretivists posit that knowledge and truth are subjective and historically and culturally situated and vary depending on participants' lived experiences. The researcher's beliefs and values cannot be separated from the research process and inevitably influence data collection, interpretation and analysis. In interpretive research there are no predefined dependent and independent variables. Rather the focus is on the complexities of human sense making as the situation emerges (Nyathi et al. 2018; Assan 2014; Bird et al. 2002; Ellis 2000; Kaplan and Maxwell 1994). Thus, in order to explore and understand the problem, and its social character and effects, it is important to comprehend it from the participants' point of view. Based on the interpretivist research philosophy, a case study approach was chosen to allow the researchers to produce rich descriptions of the phenomenon under study. Considering the complexity of the research design, participants were then selected using purposive sampling consisting of 61 A_1 farmers. Through observations and in-depth interviews, the study utilised a sample size of 57 participants and 4 focus group discussions. Specifically, data analysis included the systematic identification of patterns across data set in order to gain insights into meanings across different themes (Braun and Clarke 2012) which was useful for determining how words and word patterns are used in context (Nowell et al. 2017). After transcribing data, it was then reviewed repeatedly to identify emerging trends. The identification of themes is important in analysing interesting features of the data and collating relevant data to each code in order to understand what the data says about a phenomenon (Castleberry and Nolen 2018; Nowell et al. 2017). Hence, these were re-analysed so that they could become more refined and relevant within the given short hand codes (Maguire and Delahun 2017). The specific themes assisted in defining the names and generate themes for each variable in order to understand the overall story. Vivid and compelling examples were then extracted to back off the hypothesis and literature which helped in obtaining the sense of whole by grouping and generating categories and subcategories (Nowell et al. 2017). The use of themes enabled the researchers to quote participants verbatim to enhance trustworthiness of the findings.

3 Results and Discussion

The study sought to examine the relationship between household livelihood strategies and food security (Obi and Ayodeji 2020). Studies have shown that there is a significant difference among the landless poor, the rural households and urban residents and their motivations to engage in livelihood diversification. For instance, in the rural areas, famers engage in livelihood diversification since it allows them more opportunities to access food. The money obtained from diversification is used for meeting farm capital investment needs such as adopting new agricultural technology and the acquisition of modern inputs.

3.1 Motivation for Livelihood Diversification

H_1: In sustaining their living, rural communities that are well-off engage in few activities with higher returns compared to poorer households who engage numerous low-value activities.

Studies (Reardon 1997; Mishi et al. 2020) have shown that returns on off-farm activities are sometimes well above the returns on farming. The results show that there are various factors that influence households to diversify their livelihoods. These factors range from survival to accumulation reasons. Households pursue on farm, off farm and non-farm livelihood strategies (Barrett and Reardon 2000). The findings showed that village headship has a strong influence on livelihood diversification. For instance, those who were younger and had better education appreciated livelihood diversification that the traditional leaders who were more conservative. Traditional community leaders viewed smallholder agriculture as a tool for empowering people to come out of poverty. Agriculture was viewed as a critical path way to poverty eradication and forms part of the community's identity. Over dependence on rain fed agriculture was perceived as risky due to climate change. In order to mitigate risks related to agriculture and other disasters, better educated community leaders influence their followers in adopting diversified livelihood strategies. So, village leaders who are young guide their followers towards diversified livelihoods for mitigating agrarian shocks related risks. Observations show that the risks borne by poorer households was higher than those endured by households with high incomes. The ability to diversify livelihoods is determined by the agro-ecological position of an area. Even though farm households adopt different strategies, they are usually affected by multifaceted factors that cannot be identified empirically (Loison 2015; Mohammed 2015; Kassegn and Endris 2021). For instance, respondents indicated that off-farm diversification is influenced by vulnerability to climate change resulting in poor harvest, loss of grazing land for their livestock, infertile soils and droughts. Thus, livelihoods that were based on agriculture have been compromised due to heatwaves resulting from changing climate conditions. As a result, farmers are forced to look for alternative livelihood options. Moreover, climate variability has impacted negatively on food production, animal husbandry, and access to water. Poor rural households were found to be staying in overpopulated areas due to illegal settlements. The population growth in farms has put a strain on water availability. This has been further complicated by deforestation resulting from an uncontrolled cutting down of trees. These places have also been marred by illegal land occupation which compromise security of tenure resulting in investment on off-farm activities.

People move from one place to the other in search of better farming land resulting in livelihood diversification. For instance, house households that were motivated to diversify their livelihoods were those that received substantial amounts of cash and capital goods. Households from poorer farming communities rely on remittances from their relatives who are overseas. These remittances range from monetary benefits to inputs for agriculture.

One key informant revealed that:

> *Households in this community rely on different activities for their livelihoods ranging from animal husbandry to crop production, small scale mining a well as remittances. These activities to me are important in sustaining the needs of households involved. However, poor households without access to remittances as well as credit struggle to enter into lucrative livelihood options and end up venturing into less lucrative activities such a fire wood selling or manual labour.*

Poor households appear to use remittances to address pressing household needs such as food insecurity, while well-off households have an opportunity to invest in other livelihood options for accumulation purposes (Nyathi et al. 2018). For instance, households that are well-off receive remittances from their relatives overseas and they are capable of investing in other livelihood options. Sometimes these livelihoods options can give them higher returns. Compared to well-off households, households that are poor use their remittances to meet their day to day chores such as paying off debts, paying school fees for their children, and meeting other non-productive needs. Other factors that determine livelihood diversification include the availability of natural resources in an area and its richness. As a result, households pursued different livelihood options based on the place's natural resource endowment. The study sites are endowed with gold deposits which influenced both the poorer and the well-off households to engage in artisanal mining. For instance, Fox farm is known for Mopane worms and has become a good place for women to diversify into Mopane harvesting. Women in that area have diversified into Mopane worms harvesting since it can generate extra revenue for them in order to meet their food security needs. However, in order to generate income and meet their household needs, community members who have no alternative means to supplement their livelihoods have resorted to harvesting firewood and sand poaching. Consequently, household asset base has an influence in determining whether or not the household is able to engage in livelihood diversification. These household assets are important if one has to borrow money from the bank or other institutions that can offer credit. Findings reveal that the purpose for livelihood diversification is to accumulate assets and supplement income for households. For instance, the extent to which rural dwellers are linked to urban life style has an impact on the rural community's lives. More often, rural–urban migration offers an economic opportunity for rural dwellers as they often maintain ties with their rural origins. Other livelihood diversification determinants included education and skills training and well-being of community members. Such appeared to have an impact on the choice of livelihood.

3.2 Climate Change Affects the Livelihood Patterns Pursued by the Land Reform Beneficiaries

H_2: Extremely dry episodes are positively associated with the push factors for livelihood diversification in the western part of Zimbabwe.

Apart from agriculture, rural communities follow other livelihood options. Even though smallholder agriculture remains the major economic pathway for rural households, in all the three sites, communities were able to diversify their livelihood one way or the other. The findings show that a lot of rural households still pursue crop and animal production. Despite the dry spells, livelihood diversification in this sector has seen the introduction of crop varieties such as grain, legumes, pumpkins, round nuts and ground nuts. Due to erratic climatic conditions, some of the households have unsuccessfully explored growing tobacco and even cotton. Similarly, Nyathi et al. (2018) note that households diversify into other livelihood options such as off-farm and non-farm activities in order to cope with drought, food insecurity, the need for income and wealth/asset accumulation. New farmers have ventured into rearing small livestock such as keeping pigs, sheep and goats. Nevertheless, rural community still view cattle as a measure of wealth which is crucial in providing draught power, manure, milk, and income.

The study further showed that the newly resettled farmers relied on social grants for their livelihoods. The people who depended on social grants included orphans, old age, the bedridden and handicapped. Despite the availability of social grants, people who live on them are disadvantaged by inflation which tends to erode the purchasing power of these grants. As a social safety net, some respondents receive pensions and maize handouts. Yet, access to pensions has become a mammoth task for rural folks due to unavailability of cash in banks. The introduction of maize distribution programme by government, whilst commendable, has faced sustainability challenges since households can spend months without food handouts. There is a growing amount of literature on livelihood diversification and food security and the subject has received a lot of attention among academics and practitioners alike (Ellis 2000; Barrett et al. 2001; Escobal 2001; Abdullah et al. 2017; Kassegn and Endris 2021). Drought conditions have prompted households to venture into bio-diversity and wildlife conservation. For example, households that are participating in running the Tshabalala Game Park project have benefited from the venture. For instance, some of the participants indicated that the ecotourism projects are slowly becoming a source empowerment for the communities. Unfortunately, poorer households have found it difficult to cultivate their land due to climate change and other problems. As a result, they have started to lease their land to those who have the capacity for utilizing it. Poorer households have been forced to work as casual laborers in mines and farms. Those who worked in the farms used manual labour for survival particularly those who cannot engage in other livelihood strategies due to lack of education. Most of the rural folks are dependent on small holder agriculture which is their traditional livelihood option. Nonetheless, they also diversify their incomes for either survival or accumulation reasons.

3.3 The Contribution of Livelihoods Diversification to Household Food Security

H_3: Diversification beyond agriculture is used by households as an effective way to get alternative sources of income in order to cope with adverse environmental impacts.

There is a growing debate on the implications of diversification on agriculture and food security in the context of agrarian economy (Luvhengo et al. 2020). For instance, Patel et al. (2017) discussed the role of household livelihood diversification as an option to food security and means to produce or secure food for the people. In this study, the key to ensuring food security was found to be crop diversification. There is a correlation between households with high crop diversification and food access security. Food insecurity challenge has been compounded by the collapse of the rain fed agriculture due to climate change, heatwaves, floods as well as growing poverty, unemployment, shortage of land and increasing food prices (Clover 2003; Davis et al. 2014).

A respondent who represented Agritex indicated that:

> *Farmers are encouraged to diversify their crop patterns considering the semi-aridness of the area. When famers listen to extension workers advise, they are likely to be successful farmers. Even in bad seasons, harvests are guaranteed for those who use small grains and grain varieties. There is a close relationship between crop diversification and food security. The use of crop diversification can increase food security and improve the quality and quantity of food produced from a variety of crop species and increased food stocks. As a result, crop diversification has a bearing on crop sales, income and food consumption patterns.*

The results support the conclusions by Mango et al. (2018) who claimed that "households that diversify into higher crop and livestock intensity are less likely to be food insecure but are more likely to have diet varieties". Farmers who grow different crops and keep livestock varieties are likely to have adequate food supplies and income (Makate et al. 2017). These farmers are able to meet the requirements for food for their households. Using a diverse food crop combinations, households in study sites adopted "complementarities between crops" (Ellis 2000).The major drawbacks to crop farming are losses caused by climate change and shortage of farmland. Cattle and goats were seen as a major source for milk, meat and hides for households. Roy and Basu (2020) conducted a study in Western part of Kenya and concluded that the major reason for keeping livestock was to meet the nutritional needs through the production of milk and contribute to economic well-being of households. For instance, participants used their cattle and donkeys for cultivating their farms considering that they cannot afford to hire tractors for tilling the land.

One key informant said;

In newly resettled farms, cattle are used as a source of capital and they are very important in livelihood diversification. These animals can be used for different purposes particularly when they need money to meet the household chores such as paying school fees, hiring labour to work in the field, buying inputs for agriculture, meeting household food requirements and providing milk for young children. Cattle are important in a number of ways, for instance, they are slaughtered during social gatherings such as marriages, memorials and lobola (paying bride prize).

The anecdotes above demonstrates that the newly resettled farmers understand the significance diversifying livestock rearing practices. The above assertion shows that livestock is not reared for social prestige and household income alone but can be used for other different purposes such as ensuring dietary needs of the household and a symbol of wealth.

One of the participants indicated that:

Almost all household in our community diversify their livelihoods as a way of reducing challenges such as food insecurity. It is however imperative to not that some sources of income pursued especially by the poor are either environmentally detrimental or increasing their vulnerability to HIV and AIDs. We have a challenge of lack of capital, markets and critical livelihoods infrastructure in this area that cripples our prospects in livelihoods diversification.

Similarly, Babatunde and Qaim (2010) argue that multiple income streams are essential for ensuring food security of households. Furthermore, Devereux (2000) concluded that households that depended on rain fed agriculture were likely to pursue undiversified livelihoods resulting in food insecurity. The findings show that the higher the livelihood diversification by a household, the higher its food security status and nutrition. Therefore, climate related shocks are key push factors for diversification (Tyenjana and Taruvinga 2019).

4 Conclusion and Recommendations

Poor households broaden their livelihood scope in an attempt to mitigate negative climate vulnerabilities that have a bearing on rain-fed agriculture. Households diversify their livelihood options for either survival or accumulation purposes. Therefore, this study accepts the hypothesis that, in order to sustain their livelihoods, poor communities pursue different activities with low value whereas households who are better off are likely to pursue a few activities with higher returns. Hence, households are motivated by different reasons to diversify their livelihoods either for survival or asset accumulation. Livelihood diversification options pursued by rural farm households range from farming to off-farm undertakings. Incentives that influence farmers to undertake outside farm activities are sometimes well above the returns on farm activities. Whilst rural households can pursue other livelihood options outside farming, farming remains the pulse of the rural economy. However, there are a number of factors that can limit the level of diversification. These factors comprise environmental and economic factors, which include lack of capital and natural disasters. Therefore, extremely dry episodes are positively associated with the push factors for livelihood diversification in the western part of Zimbabwe. Although farmers are doing their best to diversify there is need for government support if they are to be economically self-reliant and resilient. The introduction of small livestock rearing has broadened the scope of new farmers' practices. Some of the households diversify their income in order to generate more income and increase purchasing power parity and capacity to buy and produce food. Whilst well to do households with assets and access to capital diversify their livelihoods for accumulation purposes, poor households embark on less remunerative diversification for survival purposes such as engaging in manual jobs and selling firewood. Such activities yield low returns and fail to contribute much in terms of enabling households to produce or buy enough food from the market. Well to do households have drilled their own boreholes for gardening, ventured into small scale mining and were also found to be the main buyers of mopane worms harvested by locals. Therefore, diversification beyond agriculture is used by households as an effective way to get alternative sources of income in order to cope with adverse environmental impacts. The study concludes that crop diversification is a key element for households to ensure food security but farmers should be educated on ways to best diversify their livelihood. Food insecurity challenge was exacerbated by the changes in agro-ecological characteristics resulting in heatwaves and floods, thereby influencing the growth in poverty, unemployment, shortage of land and increasing food prices. The study recommends that rural farmers should undertake viable livelihood strategies that enhance their well-being and guarantee dietary needs. In order to improve rural livelihoods through off-farm and non-farm activities, households should have access to inputs, lines of credit and markets.

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Holes in the Policy Net: An Analysis of Sustainable Food Production in Artisanal Fishing Communities and Policy Challenges to Ensure Long-Term Food Security in Sofala Bank, Mozambique

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1 Introduction: Setting the Scene

Mozambique is projected to become the World's second most vulnerable country to resource scarcity and climate-related disasters by 2050. It is the Sub-Saharan country facing the highest risk of ecological threats (IEP 2020). Also, it ranks 103rd of 107 countries in the Global Hunger Index (GHI 2020), making food security an essential future risk and policy focus (WFP 2020). Globally, the frequency and magnitude of climate-related impacts are expected to increase with climate change. Here, low-income countries are projected to becoming the most vulnerable (IPCC 2014). The design and implementation of climate adaptation policies to build-in resilience and disaster risk reduction are complex processes in low-income countries (IEP 2020; Mucavele 2014).

Despite political, economic, and knowledge-based challenges, Mozambique has made progress in developing its disaster risk reduction policies (Koivisto 2014) to meet climate change threats (Ferrão et al. 2018; IEP 2020; USAID 2018; WFP

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2020). Furthermore, progress has been made to achieve sustainable fishing policies, protecting fish resources and ecosystems (Ministério das Pescas 2010; REPMAR 2020). This makes Mozambique an interesting case to study such management policies' effectiveness by assessing their effects upon the actors and their reactions. The paper focuses on analyzing an essential aspect of Mozambique's future food security by addressing rural coastal communities where the primary sources of food are fishing and agriculture. We evaluate the effectiveness of existing fishing management policies and their interaction with rural fishing communities' life practices and their daily income and subsistence possibilities. This involves analyzing the interconnectedness between and obstacles faced by policy objectives and the specific characteristics of and challenges to rural coastal fishing communities' livelihoods.

We examine the following hypothesis: There are ways in which future fishing policies can ensure food security for local coastal communities and effectively regeneration and conservation of shrimp resources.

This paper defends the idea that there are untapped alternative solutions to implement sustainable and effective policies that will benefit ecosystems and human settlements. The need for climate-proof solutions is emphasized, given the strong connection between food security and climate change.

The chosen case study is a Sofala Bank Coastal community representing other fishing communities along the Mozambican coast. This anthropological study focuses on the daily practice of artisanal fishers. Coastal regions are essential when addressing food insecurity and climate change challenges in Mozambique. In recent years, they face increasing population pressure due to food-scarcity-related migration from inland areas. Here droughts have caused failed harvests and food scarcity (Mucavele 2014). Sixty percent of Mozambique's population already lives in coastal regions (Hoguane 2007; UNCTAD 2017). Of these, twenty percent depend on artisanal multispecific fishing, with shrimps being the most valuable resource. Coastal communities rely on fisheries as the primary protein source in their food diet, while small-scale agriculture is a complementary subsistence activity (Hoguane 2007; MIMAIP 2018; Palha de Sousa et al. 1995; Sousa et al. 2011).

Presently, the coastal communities are in a situation of persistent food insecurity, while at the same time, they exert constant pressure on fish resources (UNCTAD 2017). They constitute a threat to the good health and sustainability of the marine and estuarine ecosystem. Ecological vulnerability, unsustainable fishing practices, and management failures create a risk of ecosystem breakdown. An enclosure period policy has been implemented, where fishing in coastal ecosystems is prohibited for all fishing sectors (industrial, semi-industrial, and artisanal). The objective is to reduce the pressure on fish resources (REPMAR 2020).

In Mozambique, artisanal fishing is a highly ranked activity for the local labor force since it generates income and is a source of food security. Simultaneously, it has been found necessary to target artisanal fishing methods (Sousa et al. 2011), in the most recent fishing regulations (MIMAIP 2020; REPMAR 2020; Sousa et al. 2011). However, little social fishery research has been conducted to guide fishery management (Afonso 2010), such as conservation of coastal resources and artisanal sub-sector catches (Pereira et al. 2014), or fisher practices and lifestyle.

The sociology underlying the perceptions, behavior, practices, and motivational drivers of Mozambican coastal fishers is unknown. The existing data is limited. The few research analyses are based on quantitative statistical data and analyze the fishermen's responses to specific management policies (IDPPE 2013a; MIMAIP 2018; Santos 2008).

It is necessary to understand further the broader interconnections between the fishermen's behavior, policy measures, and ecosystem conservation, and the need to protect the marine ecosystem and ensure the coastal population's livelihood and sustainability. This process requires evaluating policy effectiveness by examining the everyday activities of artisanal fishers and possible obstacles on the ground. To test our hypothesis, we first address three key food security challenges in coastal Mozambique and then consider a fishing community's daily lives and practices via a case study in one of the 200 fishing centers in the Sofala Bank Delta (Fig. 1a).

2 Case Study Background and Methodology

The case study background and the physical field.

The Zambezi River is one of Africa's longest rivers and is located in southern Africa. Its sources are located on the Lunda threshold in Zambia on the border of the Democratic Republic of Congo and Angola. The river stretches for a total of 2736 km. Its catchment area is 1.33 million km^2. The river flows through Zambia, Angola, and Mozambique, before emptying into an 880 km^2 delta in the Indian Ocean (Gammelsrød 1992).

The Zambezi River is the largest of about forty rivers that discharge onto the Sofala Bank (Pereira et al. 2014). The river estuary systems of this low-lying coastal zone comprise around 200 fishing communities (IDPPE 2013b) along its 700 km coastline (Google 2021) (Google maps). It is a region with 801,590 km^2, dominated by mangrove forests as the primary vegetation.

Several rivers discharge onto the bank, with the Zambezi River being the main source of freshwater. As a consequence, the bottom topography on the bank consists predominantly of fine gravel and sand sediments from Zambezi runoff.

The Zambezi river delta is the most crucial ecological habitat on Mozambique's coast and is one of the most productive penaeid shrimp ecosystems in the western Indian Ocean (Hoguane 2007; Malauene et al. 2021). The case study area (Fig. 1b) comprises the fishing communities of Chuabo Dembe and other fishing centers and markets located near the Bons Sinais estuary. Most of the region covered is in rapid urban expansion but still retains rural characteristics. The Bons Sinais estuary crosses Quelimane, the principal city of the Zambézia province, and some fishing villages, such as Chuabo Dembe village, where the local population lives just next to the river.

According to reports from the local population, the first settlements at the Chuabo Dembe fishing village date back to the 1980s, when the civil war broke out in Mozambique. The war resulted in a massive exodus of people from the rural areas to seek protection close to cities. Because of its strategic location up-river, protected by the

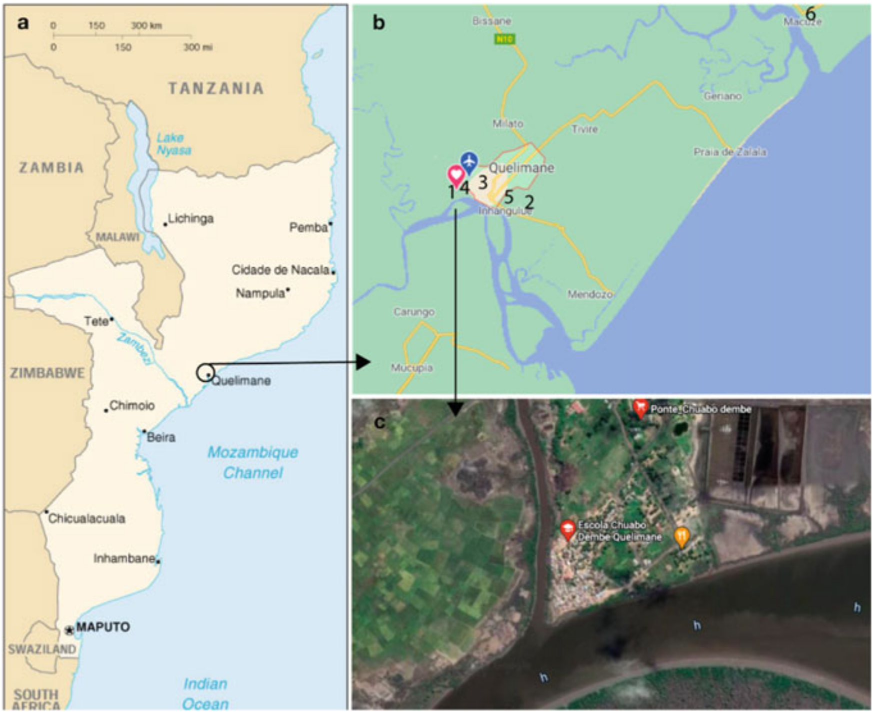

Fig. 1 **a** Map of Mozambique showing the main Zambezi River and Sofala Bank. **b** Map of the relevant communities in the Zambezi River Delta—field study locations "Chuabo Dembe village", Sofala District (1) and the five secondary fields of data collection "Icidua Fish Trading Center" (2), "Quelimane Central Market" [Mercado Central] (3), "Fai Market" [Mercado de Fai] (4), "Icidua Market" [Mercado de Icidua] (5), Sofala District, and the "Marcuse estuary", Namacura District (6). (c) "Cabo Dembe village". Data sources: FAO (2004) **a**, Google maps **b** and **c**

city of Quelimane, and its proximity to the estuary, fishers from other coastal areas started settling in the area, establishing a fishing village. The village houses are built with local material, wood extracted from mangrove trees and clay, and zinc sheet roofs (Fig. 1c). About 2 km from Chuabo Dembe is the tiny Fai Market (Fig. 1b). Here, fresh and dried shrimps and fish are sold, providing protein, mainly to the surrounding neighborhoods. The majority of the fieldwork was carried out in these two locations.

3 Methodology

The research design drew upon qualitative and quantitative methods involving literature review, anthropological participation, semi-structured interviews, and user surveys.

To test our hypothesis, we did a literature review of Mozambican fish policies 1980–2021, the penaeid shrimp life cycle, and developments in Sofala Bank coastal fishing focusing on artisanal fishing practices. The field study focused on two fishing communities and four related fish markets (Fig. 1).

The case study concentrated on Chuabo Dembe village, aiming to understand the life practices of artisanal fishers and analyze the effectiveness of fish policies on the ground. We tested our hypothesis by exploring the untapped potential of sustainable solutions for fish resource conservation and food security in coastal Mozambique.

The case study was conducted from December 2017 to August 2018 at Cabo Dembe fishing center. We followed the fishers' activity on land and on the river between January 2018 and August 2018 (36 visits), participating in fishing activities at Bons Sinais estuary from the Chuabo Dembe fishing center to the farthest point in the direction of the river mouth, covering a distance of about 10 km of the river length. The Bons Sinais estuary is about 30 km across.

Our sample included 37 fishers, which is about 40–50% of the entire fisher population. According to local fishers, there are between 70 and 96 artisanal fishers in Chuabo Dembe. According to national statistics, there are 69 nets and 60 boats in Chuabo Dembe (IDPPE, 2013a). Since official statistics do not include social variables such as age, it was less possible to analyze whether our sample was representative compared to the population (e.g., a one-sample t-test).

Both qualitative and quantitative methods were used in the present research. The main data collection source was participant observation and interviews, while catch composition samples were carried out and collected among fishers in the Chuabo Dembe fishing village (with around 250 households).

For this study, the analysis was divided between two fishing periods: (1) The normal fishing period and (2) the enclosure period for shrimp fishing. During the field study period, the enclosure period was announced on 12th November by the national fishing authorities (ADNAP). For artisanal shrimp fisheries, shrimp's enclosure period covers the period from 1st January to 28th February. During this period, it is not allowed to catch, sell, and transport shrimps caught in the Sofala bank. Furthermore, the use of nets with small mesh sizes is prohibited in estuaries and coastal areas.

Supplementary data were obtained from secondary sources, including analysis of artisanal fishing census information (IDPPE, 2013c), national fishing regulations (REPMAR 2003), decrees, and policy statements from national profile sources such as the Small-Scale Fisheries Development Institute (IDPPE), the Ministry of Fisheries (MIMAIP), the Council of Ministers, and reports from the National Institute of Fisheries Research (IIP).

4 Results

Three key challenges

Overfishing is a threat to ecosystem conservation

In Mozambique, three types of fishing contribute to 3% of BNP and 4% of exports. Commercial sectors (industrial and semi-industrial) exploit the most valuable Sofala Bank fish resources, e.g., shallow and deep-water shrimps and fish species, such as tuna, billfish, and sharks (Pereira et al. 2014). Artisanal fishing operates mainly in the shallow waters of estuaries. It is practiced for subsistence and commercial purposes, involving fishing communities and actors in the value chain, e.g., fishermen, processors, fish transport, traders, input suppliers, boat carpenters and technicians, and net maintenance (Afonso 2010). It is the most productive activity, accounting for about 90% of annual catches (MIMAIP 2019; Pereira et al. 2014). This sub-sector is of great social importance. Coastal communities, representing 2/3 of Mozambique's population. For them this sub-section is the most critical food source and also for employment (Afonso 2010; Pereira et al. 2014). In addition to fishing, the households are involved in agriculture as the second subsistence activity and exploitation of forest resources (e.g., selling firewood and coal, mainly in coastal areas close to urban centers).

Artisanal fishers operate in nursery grounds in shallow coastal waters, covering coastal environments in rivers, bays, estuaries, and shallow beaches. The fishing activity is carried out using "dugout canoes" and other non-motorized vessels. Less than 3% of artisanal fishermen's boats are motorized (IDPPE 2013b). Approximately 50% of artisanal fishers operate without the use of boats.

The fishers use different types of fishing gear, "conventional beach seine" (trawling net), and non-conventional fishing gear such as "Chicocota" and "mosquito nets" (Pereira and Brito 2008). These are all considered inappropriate fishing methods, harmful to the ecosystem and the shrimp stock (ASCLME 2012; Chaúca and Álvaro 2010; Hoguane 2007; Pereira and Brito 2008; REPMAR 2020).

Since 2000, an increasing number of non-selective fishing gear has aggravated shrimp stock decline (Chaúca and Álvaro, 2010; IDPPE 2013a, 2004; INIP 2015). Non-selective fishing gear has a small mesh size, leading to the catch of a large number of larvae and juveniles (Chaúca and Álvaro 2010), and reducing the rate of recruitment to the open sea, especially in the rainy season (Brito and Pena 2007; Palha de Sousa et al. 1995).

Penaeid shrimp live in tropical and subtropical waters. The lifecycle of the shrimp larvae starts in the ocean with adult shrimps. The post-larvae migrate to the river estuary. The estuarine environment is used to grow from larvae to juvenile (Garcia 1981), making the estuary a critical nursery ground and ecosystem for the penaeid larvae and juvenile's survival and growth. The estuary is rich in nutrition carried by the river (ASCLME 2012; Gammelsrød 1992; Hoguane 2007) and the mangrove roots retain the nutrients, protect from predators, and ensure a food-rich environment (Nagelkerken et al. 2008). The juveniles return to the sea to complete their development as adults (Dall et al. 1990; Garcia 1988, 1981).

The industrial, semi-industrial, and artisanal fishing sectors compete over the same resources. Thus, it is essential to consider all three sectors when designing fishing management solutions. Historically, the two industrial sectors have been responsible for the largest production of shrimp catches. However, from 2000 to 2019, their catches declined more than 60%, from 8755 to 3279 tons. During 2012–2013, the catches reached a low of 2000 tons annually, leading to concerns about the possibility of a fish stock collapse. On the contrary, artisanal fish catches increased almost 280%, from 1367 tons in 2006 to 6295 tons in 2018 (MIMAIP 2019, 2018).

In conclusion, the shrimp stock's sustainability is in danger if adequate policy measures are not implemented.

Current Fishing Management Policies Provide a Threat to Fishing Communities' Daily Food Supply

Due to the penaeid shrimp's economic importance, management policies were initiated during the 1960s to avoid overexploitation. Until the 1990s, regulations focused exclusively on the industrial and semi-industrial sectors operating on the open sea (Pacule and Baltazar 1992; Palha de Sousa et al. 1995; Santos 2008). For these sectors, an enclosure period has been established since 1989. It increased from 15 days to 5 months in 2020 (MIMAIP 2020; Sousa et al. 2011).

The artisanal sector, operating in the estuaries and shallow coastal waters, remained under-researched and poorly managed until about 2000 (Pereira et al. 2014). Researchers argued that the estuary is critical for the penaeid's recruitment (Chaúca and Álvaro 2010; Garcia 1988; INIP 2015; Palha de Sousa et al. 2015; Pereira and Brito 2008; Silva et al. 1995). Continuous drastic declines in the industrial shrimp catch since 2000 have led to stricter fishing regulations, also targeting the artisanal sector (Sousa et al. 2011). A three-month enclosure period for artisanal fishing has been recommended since 2010 (Chaúca and Álvaro 2010; Palha de Sousa et al. 2015). In 2014, the government implemented a one-month enclosure period (January) (IIP 2017), expanded to two months in 2018 (January and February) and five months in 2020 (MIMAIP 2020; REPMAR 2020; Sousa et al. 2011), the latter having the same number of prohibition days as the industrial sectors.

Establishing the enclosure period ensures the protection of nursery grounds for the penaeid larvae and juveniles within the estuarine habitat where artisanal fishery usually targets them. It promotes a higher rate of migration of juveniles to open sea fishing grounds. Because of this the industrial and semi-industrial sectors are ensured higher catches (Palha de Sousa et al. 2015, 1995; Silva et al. 1995), but no changes in the fish catch of the artisanal fishers. Since most of them do not have motorized boats, they don't have access to open sea fish resources (Ministério das Pescas 2010; UNCTAD 2017).

In conclusion, the efficient implementation of current management policy aims to benefit ecosystem resilience and shrimp reproduction. However, while the industrial fishing sector is expected to obtain increasing catches due to the enclosure period for artisanal fishers, these regulations do not contemplate economic support for artisanal fishers during the five months of prohibition. There are no direct incentives for the artisanal fisher to stop fishing during the enclosure period and comply with the regulatory policy. Moreover, the ongoing policy does not have a legal framework for artisanal fishers to address their immediate subsistence needs, especially their daily food needs, during the 5-month enclosure period.

Climate change is a threat to present and future food production (fisheries and agriculture)

Future food security is connected to climate change-related impacts. In Mozambican 2/3 of the coastal areas population are projected to be affected and thus highly vulnerable to rapid-onset disasters (e.g., cyclones, storms, salt intrusion, and flash floods) (WFP 2021). The latter reduces soil quality, with the associated risk for crops (via irrigation with salty river water). Thus, future food production is endangered. Additionally, this threatens the availability of drinkable water near the villages. In essence, a greater prevalence of storms in the Mozambique Channel and increasing sea surface temperature and ocean acidification will negatively affect coastal ecosystems and fisheries.

In recent years, the human pressure on coastal areas and river ecosystems, i.e., overfishing, has increased due to migration from in-land Mozambique, caused by droughts and failed agricultural harvests (UN; 2017). On the other hand, more frequent tropical cyclones and sea-level rise will amplify coastal erosion in the near-term future, threaten habitats, houses, and infrastructure, causing forced migration away from coastal areas (WFP 2020).

The coast's geomorphology is described as low areas, with a maximum altitude of about 200 m above average sea-level. In the South, the coastline is portrayed as intermittent stretches of sandy dunes, beaches, and coastal bays and lagoons; in the Center as mangrove swamps; and in the North by dense and extensive vegetation. In the North, you also find islands, rocky beaches, and coral reefs (Hoguane 2007). Thus, the area is vulnerable to sea-level rise and tropical cyclones that produce floods and destruction (IPCC 2014).

It is likely that the frequency and magnitude of climate-related threats will increase in the near and long-term future. This may cause additional pressure in Mozambique and shaping new challenges (Koivisto 2014; USAID 2018; WFP 2020). A combination of three main stressors, rising sea-levels, warming and acidification of the ocean, and increased risk of tropical cyclones, are a threat to rich marine ecosystems, human habitats, and fishing. It is causing damage to ecosystems such as coral reefs, mangroves, and seagrass, leading to biodiversity losses (IPCC 2014).

To address their food needs and livelihood income, Mozambique's rural communities are highly dependent on natural ecosystems for fishing, agriculture, and forest products. These natural resources are projected to be highly impacted in the future climate (IPCC 2014; USAID 2018; WFP 2020).

In conclusion, fishing management has to find resilient solutions to adapt to present and future climate impacts. It is crucial to improve middle and long-term adaptation to climate change to meet future food security risks, including the protection of water resources, agriculture, and coastal zones.

Case study: Artisanal Fishing Activities in the Bons Sinais and Marcuse estuaries in the Sofala Bank

I'm sitting on the canoe. Antonio has paddled six hours—three hours going out and three hours going back from the estuary's coastal fishing area. Today the water is 'agua turva' [turbid water]—visibility is less than 30 cm. The fishers would say that this is a perfect day for shrimp fishing (Fieldnotes (Halaze Manhice), September 2017).

The fishers' monthly work periods are centered around the spring tides, amounting to around 15 working days a month, depending on the tide and lunar cycles. However, the work is intense and demanding, with about 3–4 h of rest between the two daily trips to the river to set and empty the nets. In general, the men fish, while the women process (e.g., dry the fish) and sell the catches. Often women sellers buy the catch directly after the fishers arrive in the village and take it to the local market (Fig. 2).

Daily life is a struggle for food. The fishermen and their families live by the river, and their daily existence depends on what resources they get from it.

We are just arriving at the village after seven hours on the river. We see the industrial fishing boat parked by the edge of the riverbank. I know these ships go up-river to hide from storms in the open sea. We see village women, including the fishermen's wives, leaving the ship with plastic bags full of frozen fish on their heads. For industrial ships, shrimps are the primary target and fish a bycatch that is often discarded in the sea. Antonio explains that it's a recurring practice that women are invited to the industrial fishing boats. Married or not married, they get frozen fish in exchange for their sexual services. (Fieldnotes (Halaze Manhice), September 2017).

Sometimes the women sell their bodies to industrial fishers for frozen fish. This indicates the importance of fish for locals and shows how the village practices are centered on the river. In the last few years, due to reduced catches, the industrial boats have started selling the bycatch to artisanal fishers who approach the boats, and for about 400–600 meticals (€4.5–7) get 10 kilos of frozen fish to resell, especially for urban residents who can afford to pay for it.

None of the fishers are engaged in an alternative income-generating occupation, e.g., to provide income or food for their families during the enclosure period. 88% of those interviewed had no savings or any financial support. 12% of those interviewed were involved in community-saving schemes (Fig. 3).

Multispecific fishery

The shrimp is captured in a multispecific fishery where fish is the most abundant resource.

The artisanal fishery comprises multispecific catches where juveniles of penaeid shrimps are the main target because of their economic value. During the period under analysis, fifteen fish families were identified. In the catches, shrimps constituted 94% of the total number of individuals (6700 fish, shrimps, mollusks, etc.) and 64% of the sample's total weight (approximately 12 kg). This characteristic of the

Fig. 2 Artisanal fishers in dugout canoes setting nets. March 2021. *Photo* Halaze Manhice

Fig. 3 Photograph taken at Cabo Dembe village, showing how the local community dries the small shrimps (left) and mixed species of small fish on a mosquito net. *Photo* Halaze Manhice

fish catches shows the ecosystem's role as a nursery ground for those highly commercially valuable fish species and many crucial demersal fish species. A general catch composition comprises a mix of "buero buero" [a small shrimp with the same size as penaeid juveniles], small fish, mollusks, mudskippers, crabs, and juvenile penaeid shrimps (between 4 and 5 cm on average).

In Bons Sinais, artisanal fishing bycatches (e.g., buero buero, sardinella, and all kinds of small-sized catches) are used by local communities as a protein source in their food diet and to supply nearby markets. At the same time, penaeid shrimp is the main income source. In contrast, the bycatches of the industrial and semi-industrial fisheries constitute about 90% of the total catch, and most are discarded in the sea due to their reduced commercial value (IIP 2018; Sousa et al. 2011).

The fishers, boats, and gear

Two types of artisanal fishers can be identified: commercial and family. However, the fishing activity in Chuabo Dembe has a primarily commercial focus, with most of the catch being sold for resale. Additionally, the relationships between the fishers and the village consumers (sellers, traders, fishers, community members) are mainly kin relationships. All refer to each other as auntie, uncle, brother, cousin, etc., indicating close family relationships. Fishing is demanding and exhausting, and fishers are, in general, proud of their occupation.

Fishing was a family tradition for 63% of the fishers interviewed (either their father (63%) and/or grandfather (54%) was/is a fisher). 90% perceive there is an increase in the number of fishers in the area. Additionally, several more experienced fishers have noticed a decrease in precipitation during the rainy season and increased storms and floods. Some were aware of the impacts of climate change on the environment.

Besides decreasing wood availability, mangrove deforestation also harms fish and prawn populations and increases coastal erosion.

100% of the interviewed fishers were men. They had between 1 and 32 years of experience. Their average age was 32 years (between 16 and 53 years). The majority (67%) were between 16 and 35 years.

The two types of non-motorized fishing boats in use are dugout canoes and rowing boats. However, part of the fishing activity is conducted without using a boat, shallow water sites, or low tide. The most widely used 'boats' to carry out fishing activities are canoes (67%), "lanchas"/rowing boats (25%), and others (12.5%).

On average (during the fieldwork period), each net could make around 1200 meticals (€14) per day and 6000 meticals (€70) per working week (about two weeks per month). The sales and catches are divided between the owner (50%) and two fishers.

Three types of fishing gear were observed to catch shrimps in the estuaries covered by the study: (1) beach trawling, (2) the chicocota, and (3) mosquito nets.

5 Types of Fishing Net in Use

Chicocota and mosquito nets. Although prohibited, these nets are used by local fishers all year round. They are considered destructive for the ecosystem with high impacts for marine species in their early life stages, impacting stock regeneration (Chaúca and Álvaro 2010; Pereira and Brito 2008).

Chicocota is a trap-type fishing gear built and based on old netting, and takes the form of a funnel, with the bag usually made of mosquito nets, therefore of tiny mesh. This trap is placed in places with water currents at low depths, such as the mouth of rivers and other coastal areas (Pereira and Brito 2008). The Chicocota fishing gear is usually anchored in the estuary's narrow arms, secured by cables attached to both sides of the river, in mangrove trees, buried or attached to rocks.

Beach trawling is used in shallow waters, mostly with a sandy bed, involving about 5–12 fishers, several canoes, and a boat. The activity is carried out at low tide, allowing fishers to walk along the banks to perform the drag.

In general, the shrimp moving with the tide are swept with other organisms into the capture bag formed by a thin cloth.

Gillnets are allowed during the normal (legal) fishing period (April–October). Chicocota and mosquito nets are considered illegal (Ministério das Pescas 2010) and, since 2020, beach trawling is also prohibited (REPMAR 2020). As illustrated in Table 1, only three out of the 37 fishers interviewed said they use gillnets. However, we didn't observe any gillnets in use during the fieldwork period (December 2017–August 2018). We observed 40 nets in use during an average day over the two-month artisanal enclosure period (January–February). During the normal fishing period, the two illegal nets—Chicocota and Mosquito nets—were used.

Authorities do not officially recognize Chicocota and mosquito nets. Although prohibited, these nets are used by local fishers all year round. They are considered

Table 1 The use of fishing nets observed in the survey, outside, and during the enclosure period. Observation period from August 2017 to August 2018

Fishing gear		Enclosure period		Normal fishing period	
		Survey (number of respondents using the nets)	1-day observation	Survey (number of respondents using the nets)	1-day observation
Chicocota[a]	Illegal	8	15	12	22
Mosquito net[a]	Illegal	8	4	3	4
Beach seine (trawling) [b]	Allowed until 2020	8	21	22	42
Gillnet	Allowed	3	0	0	0

[a] Fishing nets that are considered illegal since the first fishing regulations
[b] According to the most recent fishing regulation (REPMAR, 2020), "beach seine (trawling)" is not allowed. However, during the field study in 2018, the nets were allowed during the normal fishing period.

destructive for the ecosystem and harmful for the fish stocks (Chaúca and Álvaro 2010; Pereira and Brito 2008).

6 Knowledge of the Law

About two-thirds of the fishers (65%) stated that they needed to have a fishing license to carry out their fishing activities, while 85% knew about the enclosure period. Furthermore, 82% stated that the enclosure period was a vital management measure, "for the fish to grow" (5 fishers), "for fish and shrimps to grow" (5), "for fish reproduction" (3), "for shrimps to grow" (1), or "to allow the fish to migrate from the estuary to the open sea" (1). Despite that, 75% of the fishermen acknowledged that they would fish during the enclosure period.

Despite awareness, the practice has not changed according to best practices for conservation management. Although they knew the law's content, e.g., the need for a license, the enclosure period, and the reasoning behind it, all interviewees stated that they fished during the enclosure period.

70% of the fishers had an opinion about who was responsible for implementing the enclosure period: most stated that it was the government (8 fishers), the Capitania or Coastal Authority (4), the Ministry of Fishing (3), the Fishery Direction (1), or the community council of fishers, i.e., the Community Fisheries Organization (1) out of 37 fishers interviewed.

7 Fishing Activity During the Enclosure Period

Based on our observations during the 2017–2018 enclosure period, we hardly saw any law enforcement officials prevent illegal shrimp fishing, in fact, only once or twice during the five months. About 200 fishing centers cover about 40 river estuaries in the Sofala Bank, making regulation activities costly and demanding. Although the law is based on scientific evidence, to avoid overfishing and support ecosystem resilience, enforcement appears impossible. The fishers also do not appear to obey the law, making the law ineffective.

When the prohibition period was decreed in January, changes were observed in the group's fishing activity at the Chuabo Dembe fishing center. Speaking with the owner to arrange the date to accompany the fishing activity, he said fishing would not happen in that month, respecting the enclosure period regulation. However, when we went to the estuary in the morning, three fishing nets were anchored, making full use of their fishing capacity.

When it was time to get the fish out of the nets, we noticed that the number of anchored nets dropped to two, and only one of the three fishers was present. The fish buyers took the two canoes instead of waiting on the bank as usual and collected the catch directly from the nets. On the bank, the fish were separated and stored in their containers. Furthermore, during the enclosure period, we observed other people responsible for organizing the fishing activities and negotiating with the fish buyers. Instead of the boat owner, this was done by a 17-year-old non-fisher.

Additionally, in January, we witnessed a lower yield from the catches compared to December. One morning, a catch comprised a mix of "buero buero" and penaeid shrimp of small sizes (less than 4 cm) and a few fish. In total, the young man asked for 190 mt (€2.15) for the entire catch.

During the enclosure period, the fishers changed the net terminology from chicocota to gillnets. They also corrected me when I called them chicocota, stating that that net was harmful. Chicocota was, in fact, used in all the estuaries that we examined. On one day, we observed about 32 chicocota and nine trawling nets, similar to the number of daily nets observed during the normal period.

8 Discussion

We investigated whether the fishery policy effectively protects the fish resources and simultaneously ensures peoples' basic needs. The case study results show that artisanal fishers operate all year round, not because of a lack of knowledge of the enclosure period's benefits, but because fishery is their primary food and income source. The policy contains no measures to address their food needs during the enclosure period. This challenge is not an isolated local problem but a national challenge (UNCTAD 2017) that also appears in other tropical areas, such as Madagascar, Tanzania, and Kenya (Cinner 2009).

The main problem with the current policy is that it does not address the challenge as a whole. It does not provide a substitute income for artisanal fishing communities and empower them to engage in sustainable conservation practices. Additionally, these management policies do not explicitly recognize that the effective conservation practices of artisanal fishers in the estuary benefit open sea fishing. Thus, the artisanal fishers do not have any motivation to comply with the enclosure period.

Open sea fishing and aquaculture

A well-known approach to reduce pressure in coastal ecosystems is to encourage and safely scale up the technological capacity of coastal fishing communities (FAO 2020a; Ministério das Pescas 2010), since it reduces the stress and pressure on estuaries, bays, and other key coastal ecosystems (FAO 2020b). However, this policy has not been implemented for more than a decade because both the government and the fishermen have faced economic and financial constraints (Ministério das Pescas, 2010).

In any case, such measures may not be enough to address future food security. As in most African countries, the fishers in the Sofala bank coastal areas rely on already overfished and declining resources (IIP 2018, 2016, 2015). Under the present circumstances, there is no driver to reach sustainability and regeneration of the fish resources. Everybody is allowed to fish, and moving fishing to the open sea can also result in overexploitation. Additionally, maintenance of motorized boats may be a challenge for artisanal fishers.

Aquaculture is another possible solution. It is estimated that there is 33 000 ha available along the long Mozambican coast. Shrimp has been pointed out as a good development opportunity since only 2.5% of the country's total shrimp production comes from this sector (FAO, 2004). There is pressure from the government to promote actions leading to fisheries and aquaculture development (Nhantumbo and Gaile 2020). Small (and medium-scale) fish farming may develop in Mozambique (Muhala et al. 2020), ensuring food security for local communities (Nhantumbo and Gaile 2020).

However, the solution may be costly and produce environmental (pollution) and ecosystem risks. Outbreaks of disease have challenged the development of aquaculture initiatives in Mozambique over the last decade. Since 2012, the country has diagnosed a highly mortal disease for shrimps (the white spot disease), which forced the three industrial farms to stop their production for years (RAF 2013) and contributed to reduced development of this activity. In 2020, a deadly virus was detected in all Mozambican industrial fish farms, posing a significant threat to the livelihoods of small-scale fish farmers and wild "tilapia" shrimp populations (Jansen et al. 2019). Thus, a legal framework seems necessary to effectively manage aquaculture fish populations' health and ensure the responsible development of aquaculture.

Agriculture as an alternative income

Most artisanal fishing communities are rural. Rural households have a great potential to develop agricultural productivity (FAO 2004). About 83% of the Mozambican labor force involved in agriculture, forestry, and fishing are women (IOF 2015).

However, in Chuabo Dembe, 100% of fishers are men, while women are involved in processing (e.g., drying fish) and selling catches at the market. Most houses have smaller agricultural plots behind the houses or near the villages, where they grow food crops, such as Cassava, for household supply.

Several initiatives are acknowledged to be essential to diversify the income of the coastal communities. The combination of subsistence food production with cash crops should be seen as an integral part of improving food security at the household level in some developing countries (Ferrão et al. 2018), particularly in Mozambique. The rural economy is potentially vulnerable to future environmental and economic risks. Here limited, and prevented, cash crops can function as adaptation actions which can create substantial salary and work opportunities (Ferrão et al. 2018).

Sisal (Agave sisalana), a cash crop naturally adapted to the East African climate, has a low demand for water and labor, is resilient to droughts, and could significantly revitalize cash crop agriculture in coastal areas. The plant produced vegetable fibers and was introduced in Mozambique in the 1940s, mainly to manufacture ropes, mats, carpets, and handicrafts. Presently, sisal can also produce polymer composites for various applications. These include geotextiles, building materials, automobiles, the packaging industry, and electrical industry (Saxena et al. 2011; Silva et al. 2008).

Change in sisal demands due to the increasing use of synthetic fibers has triggered a lack of interest and neglect of this activity. However, it could be revitalized by taking advantage of the existing production structure installed in the past in the country's central and northern regions (Galvão 2013). Sisal has the advantage of being a green material that consumes much less energy in production than synthetic fibers (Asim et al. 2017; Saxena et al. 2011). Mozambique produces about one thousand tons annually, being one of the top ten countries with the highest production worldwide, but could produce much more (FAO 2017). Additionally, East Africa has the best climate and conditions for sisal. The plant has not been affected by diseases like those experienced in Brazil (Abreu 2010).

Strengthening the interconnections between stakeholders (fishing sectors, governments, and donors).

There is a need for increased interconnection between the different stakeholders, including the three fishing sectors, because they seem to work independently from each other, with no mutual cooperation. Here, NGOs could play a key role since they now have a legal framework to intervene, according to the new community management approach of the fishing regulations (REPMAR 2020).

Historically, the tension between the industrial, semi-industrial, and artisanal sectors has increased because of declining fish stocks. Given that some environmental NGOs are assessing the ecosystem's weaknesses and trying to implement solutions, it should also be in their interests to improve the interconnectedness and cooperation between the fishing sectors.

In general, NGOs can improve socioeconomic security in local communities and address conservation of natural resources, e.g., improving compliance and promoting alternative practices.

The government recognizes all these socioeconomic and environmental challenges. However, to address those issues, insufficient budget availability has been the key struggle at the national level to enforce compliance with policies and address local communities' needs to promote behavioral change.

Most of the ongoing fishing conservation projects rely on external funding and aid from local and international non-government organizations (NGOs) and civil society organizations (OCS), owing to the government's has budget deficiencies. NGO activities are based on external funding. They may focus primarily on donor interests or demands, which do not necessarily reflect local development needs for a long-term stable conservation approach.

The investments available seem to be very limited, and it seems that this will be even more limited in the future because of the COVID-19 pandemic. Public funds must be used in the best possible way, meaning that they address the real needs of both ecosystem conservation and fishing communities' wellbeing.

NGOs are an essential link between the artisanal fishing communities, national government, and potential donors. They should have closer contact with these communities' challenges to provide practically applicable long-term and sustainable solutions. This could also improve the transparency and equity of the way donor funds are processed locally (e.g., to avoid corruption). NGOs should be more engaged in understanding the local and cultural context (e.g., understanding the needs, the cultural reality, and expectations).

9 Conclusion and Future Outlook

Current shrimp fish policies aim at ensuring future food security through effective management measures that protect the regeneration and conservation of shrimp resources. The present analysis concludes that the Mozambican fishing law addresses an important shrimp management issue by establishing regulations—an enclosure period for both open sea and river fishing—essential to ensure shrimp reproduction. However, the law is not effective. Artisanal fishers know about the enclosure period but do not obey it. A key challenge is that artisanal fishing communities depend heavily on fishing and have no alternative food supply or income during the enclosure period.

It is argued that it would be possible to implement policies that integrate the sustainability of the rural fishing communities and the sustainability of the estuarine ecosystems that sustain Mozambique's fish resources. The participation of all stakeholders, namely local communities, government, the fishing industry, and NGOs, plays a crucial role in implementing such policies. The NGOs' role needs to be reassessed, taking into account the local populations' daily life challenges and mediating between the stakeholders since they represent a link between the government, donors, and communities. To implement the fishing law effectively, alternative income or food security must be provided for fishing communities during the enclosure period. Agriculture and production of climate-proof cash crops, such as sisal, a fiber-producing plant, is presented as an alternative income-generating activity. Subsistence agriculture is already routine in the fishing communities, making it easier and more sustainable to upscale than aquaculture. Community-scale sisal plantations could be the key to effectively implementing food security during the enclosure period by providing extra income for the artisanal fishing communities. Further fieldwork is required to test the viability of this proposal at the local level.

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Cooperate to Transform? Regional Cooperation in Community Supported Agriculture as a Driver of Resilient Local Food Systems

Marius Rommel, Dirk Posse, Moritz Wittkamp, and Niko Paech

1 Introduction

The UN Sustainable Development Goal 2 calls for action to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture. Crucial ways of doing this are to "ensure sustainable food production systems and implement resilient agricultural practices" (General Assembly of the UN 2015). However, the current global food system is dominated by a different logic: it generates a quarter of anthropogenic greenhouse gas emissions (not including non-food agriculture), is responsible for three-quarters of eutrophication worldwide and for a third of global terrestrial acidification, while placing enormous demands on the global stock of biological diversity and freshwater resources (Poore and Nemecek 2018). Market concentration and the globalization of food production are seen as major drivers of these phenomena, given that the top one hundred companies account for three-quarters of all packaged food sales worldwide (Clapp and Scrinis 2017). Cooperation among large transnational companies leads to adverse welfare impacts which cartel authorities attempt to contain; this fails systematically due to market concentration. In fact, the opposite can be observed: mergers (the ultimate form of cooperation) and hostile takeovers (i.e. forced cooperation, the ultimate form of competition) both contribute to further market concentration. This dependency on global players for seeds, pesticides, machinery and crude oil leads to a systemic lack of food security worldwide.

A transformation toward sustainable, resilient, healthy and socially valuable local food systems (LFSs) appears necessary (Hinrichs 2000; Kropp et al. 2021; Mars and Schau 2017). A promising path toward this goal is proposed by *La Via Campesina*, a worldwide organization of smallholders that has developed the concept of food

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sovereignty (Wittman et al. 2010). Greater self-determination among farmers and the participation of local actors help to mitigate the risks of dependency on and exogenous disruptions to the industrialized food system. The concept of food sovereignty differs from that of food security by introducing qualitative aspects to what had previously been viewed in primarily quantitative terms. Similarly, alternative food networks (AFNs) (Barbera and Dagnes 2016; Forssell and Lankoski 2015; Opitz et al. 2017) "[aimed] at (re-) connecting food producers with consumers have gained increased attention in the arena of international policy and research" (Opitz et al. 2019: 22). Both movements have served to strengthen regional resilience, giving local food actors the ability to "[absorb] disturbance while undergoing changes to retain essentially the same functionality, structure and identity" (Sage 2014: 257).

One significant innovation that has emerged as part of the AFN movement is that of Community Supported Agriculture (CSA). CSA creates a direct relationship between producers and consumers that facilitates greater social cohesion (Bloemmen et al. 2015; Groh and McFadden 1997). Its basic feature is communal financing of the farm's budget. The members of a CSA jointly cover the farm's operating costs (including an appropriate wage/salary for the farmers) for one season or year through regular (usually monthly) contributions (Galt et al. 2019). In return, the members receive a "proportional harvest share, typically on a weekly basis" (Opitz et al. 2019: 23) which may be subject to seasonal and weather-related fluctuations. Thus, the members "share the risks and benefits associated with the uncertainty of farming" (Brehm and Eisenhauer 2008: 95) by adjusting their consumption to the farm produce available. Since this form of financing requires mutual trust and dependable participation, farmers generally disclose their cost structure as well as their standards of production, thus enabling a "system of transparent co-financing of farm operations" (Carlson and Bitsch 2019: 3). Furthermore, opportunities for mutual exchange (meetings, farm festivals, practical and digital collaboration) enable direct relationships between producers and consumers as well as between consumers themselves, serving to embed the activities of CSA farmers and stakeholders in a set of shared social relations (Hinrichs 2000; Opitz et al. 2019: 23; Venn et al. 2006). This mitigates the separation between producers and consumers, the latter becoming "prosumers" (Paech et al. 2021). The resulting social cohesion has proven to be a stabilizing factor of CSAs (Antoni-Komar and Lenz 2021). Barriers related to financial access are often reduced through special pricing mechanisms based on solidarity between prosumers. In so-called *solidarity-based financing* or *bidding rounds* (Krcilkova et al. 2019), members decide on the amount of their individual contribution, considering their own personal needs as well as their willingness and ability to pay (Blättel-Mink et al. 2017: 417). Individuals or households with higher incomes are invited to ease the burden on financially disadvantaged members by paying a higher contribution. In this way, costs are shared according to need and in a spirit of solidarity (European CSA Research Group 2016).

In view of the ongoing decline in the number of farms in Germany by 12% over the last 10 years and the resulting concentration of farmland (Statistisches Bundesamt 2021), this paper elaborates on German CSA-run farms as a promising economic model that may reverse this trend. Many studies have addressed the multifunctional effects of CSA and its potential for transforming the food system to achieve greater food security, food sovereignty and regional resilience (Lamine 2015; Matzembacher and Meira 2019; Worstell 2020). CSA can "take different forms as farmers and members shape it to their own needs and expectations" (Samoggia et al. 2019: 1). This results in various locally adapted types and configurations (Koretskaya and Feola 2020). In the 1980s the first producer-led CSA in Germany was set up near Hamburg. Subsequently a second type, consumer-led CSA, has increasingly sprung up, especially around urban areas. More recently, a third type of CSA is emerging, where producers and consumers are formally linked, often through the organizational form of a cooperative. Generally speaking, the number of CSA-run farms in Germany has been growing continuously for about ten years. With currently 344 CSAs in Germany and another 80 initiatives in the course of formation (Netzwerk Solidarische Landwirtschaft 2021), the market share of CSA is marginal in absolute terms. However, there is considerable potential for increase, as there is at least one CSA farm in almost every German region (Paech et al. 2021; Rommel et al. 2019).

We assume that small-scale economic units such as CSAs can be strengthened by forms of local cooperation, thus stimulating a transformation of the food system (Paech et al. 2021). By operating with greater self-determination, food businesses with a local or regional focus such as CSAs can support local food sovereignty. Recent studies have found that farmers who interact directly with consumers generally have a greater need to cooperate on account of their typically being geographically isolated and lacking either the time or the skills to market their produce compared to those who grow commodity crops (Che et al. 2005). However, barriers such as the lack of infrastructure and of financial or institutional support inhibit cooperation (Vogt and Kaiser 2008). To have an incentive to cooperate, "initiatives need to know that the resources they expend will ultimately provide beneficial outcomes that are important to them" (Miller and McCole 2014: 73).

In this sense, the role of regional cooperation between CSAs and other AFN-related actors has not yet been comprehensively analysed. We therefore analyse:

> *How does regional cooperation affect the development and diffusion of CSA and thus a potential shift toward more extensive coverage of regional food supply?*

To analyse the relevance of CSA-specific regional cooperation in transforming LFSs we (1) use transdisciplinary methods to elaborate a systematic framework that draws on the theory of (a) organizational fields (DiMaggio and Powell 1983) and entrepreneurial ecosystems (Cohen 2006; Mars 2020) to answer the question "Who cooperates?"; we use (b) a multi-level approach (Geels 2002) to gather knowledge about "Why does cooperation occur?"; and we draw on (c) the theory of inter-organizational relations (Phillips et al. 2000), supply chain collaboration (Matopoulos et al. 2007) and transaction cost economics (TCE) (Williamson 1991) to account for "How does cooperation take place?". We then (2) examine the various forms of regional cooperation regarding their potential for promoting the diffusion of CSA by conducting several interviews with experts and practitioners of German CSA organizations.

2 Theoretical Background

Understanding inter-organizational relations within LFSs in which CSAs are embedded requires that we look at (a) the actors: who interacts with whom; (b) their respective intentions: why this interaction is being pursued; and (c) how the specific interactions occur.

(a) The relevant actors can be identified by applying the theory of entrepreneurial ecosystems. This concept describes “a diverse set of inter-dependent actors within a geographic region that influence the formation and eventual trajectory of the entire group of actors and the economy as a whole” (Cohen 2006: 2). It is generally used to “identify and illustrate the implications of connections between the various organization-types (e.g. businesses, government agencies, community-based and non-government organizations) that compose entrepreneurial systems” (Mars 2020: 55). At the centre of this approach lies social capital (Bourdieu 1986), as it “brings greater structural durability to entrepreneurial ecosystems and the clusters within, by nurturing shared identities, cultures, and support networks between entrepreneurs, ventures, and other relevant actors and organizations” (Mars 2020: 56).

A similar approach is taken in the theory of organizational fields. An organizational field is a set of organizations “that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organisations that produce similar services or products” (DiMaggio and Powell 1983: 148). Organizational fields are thus composed of competing and cooperating organizations that offer similar products and services on the horizontal axis as well as organizations upstream (suppliers) and downstream (processors/consumers) in the value chain on the vertical axis. We define horizontal cooperation as “an agreement or concerted practice […] entered into between companies operating at the same level(s) in the market” (European Union 2001: 2). A third type of actors are formal and non-formal agencies, hereafter named agricultural service providers (ASPs), that monitor and influence the actions of these organizations (Mars and Schau 2017: 408). CSA-related organizational fields require “that coordination, communication, planning, negotiation, and reconciliation occur between actors and groups” (Mars and Schau 2017: 408).

(b) Cooperative endeavours in the CSA context are usually built on shared ideals, with the participants jointly tackling broader objectives such as overcoming industrial agricultural structures that perform poorly in terms of sustainability. Based on Geels’ (2002) multi-level evolutionary framework of niche activities, socio-technical regimes and global trends for emerging system innovations, Loorbach (2004) develops a cyclic management model of four components to govern systemic transitions: “(i) problem structuring, establishment of the transition arena and envisioning; (ii) developing coalitions and transition agendas (transition images and related transition paths); (iii) establishing and carrying out transition experiments and mobilizing the resulting transition networks; (iv) monitoring, evaluating and learning lessons from the transition experiments and, based on these, adjusting the vision, agenda and coalitions" (Loorbach 2010: 172). Drawing on such a transition agenda for LFSs, CSA projects benefit from multi-actor relations as they are able to incubate change while *enabling* their transformative operations. Moreover, the cyclic management that guides a system innovation out of a niche implies *stabilization* and continuous *development* (of CSA) as necessary requirements for the actor constellations (Geels 2002).

(c) While many CSAs have built up a self-contained chain of value and distribution, thus functioning more or less independently, others face the challenge of diversifying their output. Some are simply not capable of supplying a sufficiently diverse range of products due to constraints in the production facility, while others risk overburdening their members with high production costs when expanding on-farm production becomes overly expensive due to the inability to exploit economies of scale (Galt et al. 2019). The underlying conflict comes back to the issue of "make, buy, or cooperate" as Williamson (1991) argued in his Theory of Transaction Cost Economics (TCE). TCE defines an optimum organizational governance structure that "achieves economic efficiency by minimizing the costs of exchange" (Young 2013: 2497). These depend mainly on the specific assets involved and the degree of uncertainty of the transaction (Ciliberti et al. 2020). Minimizing transaction costs appears to be crucial in terms of a CSA's decision to either enable on-farm production, to outsource production and buy in products from the "market", or to find a hybrid cooperative form. All these forms result in transaction costs, either internally or externally, always in addition to production costs. This makes it necessary to weigh up the overall costs of diversifying the product range, whether this is done via on-farm production, external market supply or cooperation. Thus, the specific mode of inter-organizational interactions often arises from the necessity or motivation to expand the product range. The motivation for inter-organizational relations also arises from other sources, such as working together toward and lobbying for shared (political) goals, or reducing costs by sharing machinery and experience.

It turns out that inter-organizational relations differ in terms of context, intensity and the characteristics of the relationship between the partners. Contrary to competition, cooperation links actors over the longer term by way of contracts, agreements and regular meetings. Cooperation that highlights the congruence of values and goals, such as a non-market approach, is more specifically considered a collaborative relation and, "consequently, is governed by some negotiated alternative to the price mechanism" (Phillips et al. 2000: 24). Collaboration describes "a co-operative relationship among organizations that rely on neither market nor hierarchical mechanisms of control" (Phillips et al. 2000: 74) in order "to advance a shared mission or purpose concerning local agriculture and food" (Miller and McCole 2014: 75).

On this basis, we consider every inter-organizational relation that goes beyond a mere exchange of goods and services as cooperation, while collaboration goes even further, referring to concrete actions taken together.

3 Research Design

Following the concept of transformative research (Jahn et al. 2012; Levkoe et al. 2019; Schäpke et al. 2018), we see our study as a contribution to the co-creation of applied knowledge together with stakeholders.

3.1 Data and Methods

In order to deepen our understanding of regional cooperation in CSA in Germany we applied a range of empirical methods. We examined existing approaches to the analysis of cooperation strategies in the sphere of CSA. In addition, we gathered and analysed our own empirical data. To obtain well-grounded knowledge we used a two-stage approach to data collection based on self-selection as a sampling method (Sharma 2017):

(1) The majority of all German CSA-run farms are members of Germany's CSA network, which organizes a network meeting twice a year and offers a representative picture of the German CSA movement. An empirical method for three of these bi-annual network meetings was co-designed with the network, consisting of two presentations, four participant observation sessions (Czarniawska 2014) at workshops, and two transdisciplinary workshops, one of which used a participatory approach to stakeholder mapping in the setting of a "world café"[1] (Löhr et al. 2020) on the topic of ASPs. Two further conference meetings organized by ASPs,[2] which were similar in character to the CSA network gatherings, were used for additional data collection: one presentation, two transdisciplinary workshops and five participant observation sessions at workshops. We recorded our observations at these meetings (general perceptions and plenary discussions) in research diaries.

(2) Based on this data, we identified specific CSA projects engaged in various forms of cooperation. In four cases, we conducted additional expert interviews (Bogner et al. 2009) with representatives of the CSA projects and corresponding

[1] The aim to create a café ambience for an open but intimate discussion is what gives the "world café" method its name. It is a participatory approach that "accesses the views and knowledge present within a larger group of people" (Löhr et al. 2020: 1).

[2] One conference of the formal German rural development organization dvs (*Deutsche Vernetzungsstelle Ländliche Räume*) and another conference of the non-formal actor CSX network, which seeks to transfer CSA ideas to other business sectors.

ASPs. In a fifth case we co-designed (with a practitioner) a presentation on horizontal and vertical cooperation, using the method of social learning in communities of practice (Wenger et al. 2002). This was carried out as a webinar with question-and-answer sections. In total, our data collection consists of twenty empirical studies conducted with participants from approximately 90 CSA farms.

Apart from two events in the spring of 2020, the events and interviews in 2020 and 2021 were conducted online due to the CoViD-19 pandemic. However, we assume no bias effects on the process of data collection.

4 Analytical Framework

The three dimensions already outlined will now be further specified for the CSA context (Fig. 1):

(1) Who: Who is involved as an actor?
(2) Why: What are the functions of the inter-organizational relation?

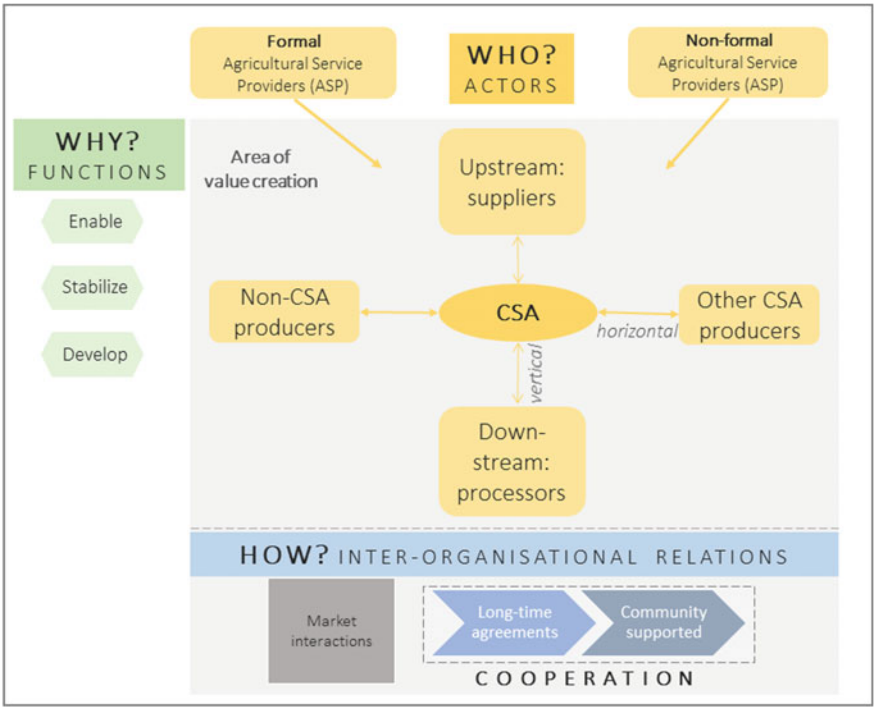

Fig. 1 The organizational field of CSA (authors' illustration)

(3) How: What forms of inter-organizational relations are involved?

(1) Inter-organizational relations occur either vertically along the regional value chain[3] between CSAs and suppliers (upstream) and consumers (downstream), or horizontally between CSA projects and other food producers in a region (organized either as a CSA or as an ordinary producer). Apart from vertical or horizontal interactions, recent research has assigned ASPs a significant role in advocating for and supporting CSA (Paech et al. 2021). ASPs act as change agents (Rogers 2003), incubators, intermediaries, catalysts or mediators, and support CSAs with specific services such as consulting, networking or access to financial capital. ASPs can be either formal institutions in politics and administration, especially at the local level, or informal initiatives from the NGO sector or civil society, as well as businesses.

(2) The present study focuses on three functions performed by inter-organizational relations between CSA and other actors.

(a) **Enabling |** Procurement of resources: For CSA actors looking to offset the economic disadvantages of a transformative economy, cooperation, respectively external support is a viable option. Resources can help a farm business to acquire acreage, capital, skills, a public profile, and other factors of production. This function is particularly important in start-up processes.

(b) **Stabilizing |** Stabilization of operations: The survival of CSA farms depends on mastering a specific situation involving three potentially conflicting goals. The first of these is to survive economically in the face of size and technology-related cost disadvantages. The second is to safeguard the social stability of the construct, especially since non-hierarchical structures and the need to coordinate informal workers can be very time consuming, which reduces productivity. This problem increases with the number of people to be coordinated, i.e., the size of the CSA, which consequently cannot exceed a certain size. This in turn means that the minimum size required to cover costs may not be achieved. Should those involved consider implementing processes of professionalization to resolve this trade-off, the transformative character of the CSA farm is in danger, because professionalization usually means a return to hierarchical structures and a traditional business logic. Cooperation can overcome this conflict by enabling not just experiences to be shared but also the procurement of otherwise cost-intensive advisory services.

(c) **Developing |** Development and innovation: The joint development of new farm products as well as the optimization of farming processes also

[3] Being a multifunctional actor, CSAs' value chains incorporate not only food but also other "products", such as education, as when CSAs intentionally serve as a place of learning. In this case, schools or other educational institutions can also be regarded as regional partners in the value chain.

highlights the advantages of cooperation between CSAs and other transformative forms of business. This can also mean establishing permanent regional supply networks based on the presence of food providers and processors whose activities complement one another mutually. Joint public relations campaigns could be another measure for a supply strategy to strengthen organizational resilience. This also requires those involved to join forces in favour of radical transition in the agricultural sector.

(3) The form and degree of inter-organizational relations may differ due to the concrete relationship of the participating members, the amount of information sharing, and the overall level of involvement (Mittal et al. 2017). In contrast to market interaction, long-term agreements involve direct relationships, long-term and stable forms of interaction, and a continuous process of direct communication (e.g. agreements about quality and fair pricing for organic seed production and long-term supply).

Against this backdrop we propose the term community supported cooperation (CSC) to refer to a level of collaboration which may fully circumvent the market's price mechanism. The actors involved remain independent and do not pay for a specific product, but jointly finance production and also share the associated risks. We assume that this kind of cooperation has the greatest transformative potential for enacting the shift toward regional resilience and food security. For this reason, our study focuses especially on CSC relations by presenting examples that are organized in this way.

5 Results

In the following, we analyse empirical observations within the organizational field of CSA. Although cooperation is not yet a dominant strategy, it is certainly an emerging phenomenon. We found cases of vertical and horizontal cooperation between CSAs as well as cooperation between CSAs and ASPs.

5.1 Vertical Cooperation

Most CSA farms buy seeds from specialized traders with organic standards. Depending on the plant type, many CSA farms (such as some in the federal state of Hesse and some near Bremen) also manage their own seed stock by producing seeds from the previous generation of crops. In addition to these common seed procurement methods of either market interaction or individual seed production, the German CSA network is in the process of setting up a seed sharing system, organized as CSC by and for the participating CSA projects. This potentially lowers production costs and places a key emphasis on greater sovereignty in farming. As well as enabling farms to operate autonomously from the seeds market, seed share systems are potential hubs for higher levels of biodiversity in that they encourage growers to conserve old varieties and acquire seed production skills to develop new CSA practices. Seed saving and sharing can be a means to disseminate CSA principles along the value chain, as the example of "community-based plant breeding", a form of open source seed production, shows (Kotschi et al. 2020).

Another significant input to the value chain, labour, is related to a further CSC model: several CSA farms have formed regional networks that provide self-organized, independent training in vegetable growing. The trainees work on cooperating farms and form annual training groups to conduct modular seminars and exchange knowledge. Conducted in cooperation with the national CSA network in Germany, this training is organized by the trainees themselves in response to a high demand for CSA qualified staff and enables the general development and diffusion of CSA.

Downstream operations in the value chain, such as the processing or manufacturing of products, serve to diversify the range of products, to preserve food for the off-season and to manage the occasional case of over-production. Varieties of pesto, jam and salsa are typically produced within CSAs. In terms of inter-organizational relations, bakery operations, for example, remain an exception. A farm in the Palatinate region that has become a CSA already had its own bakery, which is still partly separated from the CSA. This is necessary because there is too much grain to supply CSA members exclusively. Therefore, the bakery additionally sells its products directly to consumers. However, this apparently pure market approach has been slightly adapted by integrating certain CSA-derived elements, namely, the bakery provides bread exclusively on a pre-order basis with specified weekly pick-up days. Thus, in addition to influencing the customers' consumption behaviour, the bakery reduces its own operating costs by being able to predict the required production and by employing fewer staff.

In the region of Freiburg in the southwestern corner of Germany, a CSA farm has implemented CSC with a local community-supported bakery, which provides a weekly share of bread to their members. The CSA produces various types of grain for the bakery at a fixed amount on an agreed area, accounting for 80% of the CSA's crop production. Through this CSC the bakery can state its preferences to the farmers regarding the types of grain to be grown. In addition to gaining a reliable trading partner, the CSA farm benefits from an additional element of financial security in the case of crop failure. The community-supported bakery benefits to some extent from the pick-up point structures of CSAs in the region. In addition, some of those involved work in both community-supported organizations. This demonstrates the synergy of actors and the potential of CSC within local value chains and AFNs.

5.2 Horizontal Cooperation

The spectrum of inter-organizational relations in CSA ranges from market-based solutions to long-term contracting and CSC endeavours such as multi-farm CSA set-ups.

The rising number of CSAs in Germany highlights the potential for expanding a CSA's product range by engaging in new forms of regional cooperation. Many of these forms of cooperation fall short of our definition of CSC but nonetheless use pragmatic ways of establishing long-term agreements. Although there is still hardly any cooperation in the area of production among CSAs located near one another, we were able to find one example. Here, two farms share their machinery and food crates as well as, in some cases, their workers – without financial compensation – and thus mutually strengthen their organizational resilience. A more common practice consists in directing those interested in becoming a member of one CSA to the neighbouring CSA if the first one is unable to offer them membership. This cooperative practice stabilizes the economic viability of both CSA farms. In contrast to the principles of solidarity found in CSAs, competitive relations may also occur between them. One example was a potential conflict in a part of northern Germany in which a comparatively large CSA felt threatened by a CSA start-up that intended to become similarly large or even larger.

To illustrate multi-farm CSA set-ups, we present two examples of CSC between several farms forming a CSA, one near Kiel (northern Germany) and one near Nuremberg (south-eastern Germany). In the Kiel case, members receive a range of products from several farms. The joint operations of these farms are financed by a single common solidarity-based pricing mechanism that includes all the members. In the Nuremberg case, the members themselves decide which products they would like to receive in return for their financial contribution. The CSA merely provides the organizational framework in the form of an online platform via which several local farmers offer their products to the CSA community on the basis of different partnership models.

After the initial start-up phase, the issue of extending a CSA's product range through cooperation becomes increasingly relevant. In addition to receiving their weekly share of the harvest, it is common for several members of a CSA to jointly order specific products such as coffee, cooking oils, or even non-regional fruit through direct purchase or via CSC. In the case of the CSA near Nuremberg, members can order products such as animal skins or asparagus from specific local farmers and citrus fruits from an Italian CSA. These orders generally follow a market-based logic. However, regular interaction and personal contact to the producers reduces both sides' dependency on fluctuating market mechanisms. In addition to these specific purchases, the CSA has established a subscription model for bread products by cooperating with a local bakery. This demonstrates that CSA does not rule out selective market interactions. One of the organizers justifies this combination of marked-based relations and a separate community-supported structure in terms of the partnership between a CSA farm and a non-CSA business having the potential to spread CSA principles more widely.

Another CSA project near Stuttgart has implemented a food co-op in the form of an online shop exclusively for its members, involving a long-term agreement between local farms and the CSA members. In addition to the regular range of vegetables they receive, all the CSA's members can buy additional products such as cereals, bread, lamb meat or herbal teas from certain local farms on a quarterly or monthly basis. In order to share the risk collectively with the cooperating farmers, additional products need to be ordered beforehand and are available through the pick-up point structure on a specific date. Even though the cooperating farmers do not distribute their products exclusively via this channel, they benefit nonetheless from certain CSA principles: a more stable income and a steadier demand that makes production planning easier. This form of cooperation through networking also helps CSA principles to be diffused throughout the region.

5.3 Agricultural Service Providers (ASPs)

A third level of relevant interaction is the support of institutions that can be described as agricultural service providers, or ASPs. Our studies revealed a broad range of ASPs that either serve—or (from the CSA practitioners' point of view) should serve—CSAs. We highlight just a few of them as examples.

As a non-formal ASP, the German CSA network offers largely free management consultancy, arranges support in the case of specific challenges, and facilitates contacts to longstanding pioneering CSAs for the purpose of exchanging information and gaining inspiration. Food policy councils are also helpful partners when it comes to providing coordination, networking, lobbying and initiating services: they can facilitate dialogue and offer a platform through which AFN-related actors such as CSA farms gain greater publicity and attract new members or consumers. We found a promising example of an ASP in western Germany, known as *Regionalwert*, or "local value". This organization promotes regional and organic businesses, mediating between local food initiatives and ethically-oriented investors. It cooperates with several CSAs in the region, supporting them in various ways. With regard to the procurement of resources, for example, *Regionalwert* organizations have become involved in (a) investment in and leasing of land, (b) the provision of capital for farm buildings or smaller investments such as greenhouses, (c) support with staff recruitment, and (d) the facilitation of pick-up points for members. These measures, along with the dissemination of information through the *Regionalwert* network, help to stabilize CSA operations. When a CSA has harvest surpluses, the network is used to advertise for new members. It serves as an intermediary that sounds out potential partners for vertical or horizontal cooperation. CSAs also benefit from the public relations work done by *Regionalwert*, which seeks to increase demand and to improve regulatory conditions for local food provision. In terms of development and innovation, one local *Regionalwert* organized a start-up process in which an existing farm was reorganized to become a CSA farm. This farm was supported through an intensive consultation process. Holistic approaches of local ASPs such as *Regionalwert* are still an exception. Nonetheless, they serve to manifest the potential of co-creating entire regional AFNs.

6 Discussion

In our study we assessed the potential of regional cooperation to support the stabilization, diffusion and development of CSA, assuming that this leads in consequence to a greater degree of regional resilience, food security and food sovereignty. Our findings show that there are significant and increasing efforts among German CSAs to engage in cooperative relations with other actors in their region. This finding is similar to those of other studies that have looked at the development of CSA in other countries. Naturally, our study entailed a number of methodological restrictions that need to be discussed and considered when designing further research.

6.1 Effects of Regional Cooperation

Our findings support previous research (Galt et al. 2012), namely, that inter-organizational exchange enables a more comprehensive supply of food products within CSA projects, making them more attractive to (potential) members. Regarding product diversification, on-farm production depends on the CSA members' willingness to cover the additional costs or engage in voluntary work. However, the latter option generates internal transaction costs (whether financial or otherwise) due to the need for coordination. Our findings imply that these additional transaction costs should not outweigh the cost savings of volunteer labour.

When a CSA farm cannot produce a sufficient range of products for its members, sourcing products on the market is usually done only as a last resort, because it is generally seen as contradictory to the aim of overcoming market mechanisms. Cooperation with other AFN-related producers therefore seems an obvious solution. Yet our study shows that in many cases market-based relationships still seem necessary. Further research is needed to assess whether CSA members think this corrupts the idea of CSA and should be avoided or whether they see it as a "necessary evil" that helps farms to survive.

Regarding the unique institutional arrangements of CSAs, economic risks are shared among the CSA's members, whose financial contributions (the farms' revenue) are pledged in advance and serve to secure the farms' financial situation. Remarkably, the same goes for CSC with other partners along the value chain. This proves that risk-sharing in the context of CSA occurs not only in B2C but also in B2B partnerships.

Our findings also indicate that long-term agreements tend to convert into CSC over time, generating the most striking resilience-related impact of regional cooperation.

CSC enables production that would otherwise be uncompetitive in the free market. This applies, for example, to seed production and traditional bakeries that source their grain from local farms and are systematically displaced by convenience bakeries supplied from outside the region. When CSC is not possible, the second-best option seems to be some other way of working together or even sourcing products from the market, provided that this is done in a way that does not fundamentally contradict the CSA concept or alienate the members (some of whom may cancel their membership).

It is possible to identify various functions of ASPs in the CSA context: ASPs enable CSAs to become established by providing land, capital, (material) infrastructure, knowledge and public relations support. They also help CSAs to handle issues of organizational stability and to develop themselves further by initiating dialogue within a wider network. They also offer professional consultation. However, it turns out that the ASPs (especially formally constituted ones) potentially most suited to take on these roles do not yet do so. Our findings indicate that support from formal ASPs could potentially lift CSA out of its niche.

6.2 CSA Cooperation Outside Germany

Looking to the international context, examples of regional cooperation through CSA are found in many countries (European CSA Research Group 2016). At a time when the German CSA network had not even been founded, the development of CSA in the United States had advanced so far that cooperation between several CSAs was widely practised. A handbook for multi-farm CSAs was published in 2010 to provide producers with the "how-to's and nuts and bolts of setting up and operating a cooperative CSA" (Perry and Franzblau 2010: 1). A historical view suggests that regional cooperation is part of the core of the CSA concept, as "[b]oth of the founding U.S. CSAs were multifarmer operations, with several growers working together on a shared piece of land" (Perry and Franzblau 2010: 17). A 2012 study of horizontal cooperation between several CSAs lists a variety of positive impacts: the ability to better meet consumer needs, to stabilize farms, to foster regional social cohesion and organic quality (Flora and Bregendahl 2012). A more recent study of CSA in the US shows that cooperation potentially increases the distance between producers and consumers (Woods et al. 2017). Finding ways to prevent this loss of direct connection seems essential for CSA farms engaging in regional cooperation.

Japanese CSA groups (known as teikei farms) offer a surprising example of the possibilities for horizontal cooperation. In the face of the 2011 Fukushima nuclear accident, teikei farms found a way to "handle radiation risks through cooperation from teikei partner farmers" (Kondoh 2015: 151).

Regarding the role of ASPs, the case of Austria provides an interesting example: "Since 2014 there is cooperation between the organic farmers' association, Bio-Austria, and the federal government of upper Austria to actively inform farmers and consumers about alternative food networks like foodcoops and CSAs" (European CSA Research Group 2016: 14).

6.3 Limitations

Our research is subject to limitations. Qualitative research provides no robust basis for fully representative findings. Furthermore, we did not capture the entirety of CSAs in Germany, which further reduces representativeness. In addition, our sampling method of self-selection has the disadvantage that it only targets certain people and thus does not allow for variance maximization (Patton 2002). However, it can be assumed that the large number of surveys conducted in different contexts sufficiently reduces this bias. Supplementary studies have already started, in particular a comprehensive quantitative survey of all CSAs in collaboration with the German CSA network. An additional evaluation of the finalized framework by practitioners is planned as well.

Finally, further research could usefully explore whether the inter-organizational relationships we have examined can also be applied to cooperation with ASPs. Our research suggests that inter-organizational cooperation promotes greater regional resilience. It makes sense to test this supposition by means of a quantitative study of the ecological, social and economic effects of regional cooperation. The importance of CSC should not be overestimated given that on-farm production, regular buyer–seller relationships, and long-term agreements are typically used to establish an acceptable range of products. Although our research was less focused on continuing competitive relationships, these are still relevant. Further research based on studies in the US (Galt et al. 2016) could usefully supplement our analytical framework.

7 Conclusion

Our analysis suggests that regional cooperation affects the development and diffusion of CSA. It promotes (1) its stabilization, (2) its diffusion, and (3) a more extensive coverage of regional food supply. In this way it contributes systematically to an increase in regional resilience generally (considering its effects on awareness-raising, social cohesion, etc.) while specifically promoting food sovereignty in a qualitative sense and food security in a quantitative sense.

Beyond normative orientations in terms of ecology, social integrity, resilience and democratic participation, the cooperative relationships in the area of procurement highlighted in the present article open up two further economic perspectives. At least in the food sector, a return to small and decentralized structures of production seems possible. These have previously been associated with models of perfect and atomistic competition. In the context of the market economy, such cooperative relationships have been ascribed a high welfare-increasing impact based on the benchmark of efficiency. Oligopolistic or monopoly markets, on the other hand, have been said to have welfare-reducing tendencies due to cooperation (in particular price and quantity agreements) being used to exercise market power. Surprisingly, this dichotomy of welfare and competition theory is turned on its head twice by CSA: small production units are systematically predestined to establish cooperation in order to survive, and at the same time this generates the highest conceivable welfare effects. Is it possible that CSA constitutes a decentralized and sustainable model of food provision that is not only viable (despite its small production units) but can also defy competitors by enabling cooperation that acts as a substitute for economies of scale?

Thus, mutual cooperation as part of a network could enable entrepreneurial "Davids" to successfully confront overpowering "Goliaths". The fact that more and more examples of CSC exist can inspire the emergence of new CSAs as well as closer cooperation. This strategy is reproducible, yet depends on idealistic individuals or groups capable of putting the concept into practice despite the difficulties involved.

In addition, ASPs could act as promoters of both the development of CSA and their mutual cooperation. Chambers of Agriculture and similar authorities could act as change agents to promote emergence and diffusion processes, not only of CSA in particular, but of AFNs in general. If (European) agricultural policy were to focus on such a strategy of small units, for example by financing a network of ASPs, a resilient and sustainable food supply might possibly be achieved with a fraction of the current budget.

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Sustainable Agriculture and Food Security: Advances in Research and the Role of Governance in Latin American

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1 Introduction

Addressing global food supply and distribution chains is a complex endeavour, mainly due to the adversities encountered along the way, since it involves several agents and components in the fields of production, stock, international trade, supply, demand, diversification of consumption patterns and unrestrained growth population, impacting and affecting the overall general food supply and consequently global food security (Udmale et al. 2020).

When it comes to Latin America, the comprehensive discussion of food security emerges, as it is a region with a large population that includes places such as Mexico, countries in Central America and countries in South America, the region of Caribbean. It is noteworthy that these territories are similar in terms of climate, biomes, population disposition, politics, economy and culture. (Camargo and Lobos 2016).

In the last 30 years, studies have shown that data related to hunger have drastically decreased in Latin America, however, the survey of information from the Food and

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Agriculture Organization (FAO), published in 2020, pointed out that there was an increase in food insecurity in the last 5 years, particularly in vulnerable communities. In 2019, it was found that more than 57 million people in Latin America and the Caribbean were suffering from serious risks related to food security, that is, they did not eat or lack nutritious food (Espinosa-Cristia et al. 2019; FAO 2020).

Governance work can be understood as problem-oriented, context-specific and people-centered. It seeks to clarify the political nature of a problem, identifies the primary issues and involves all relevant stakeholders to arrive at feasible solutions, as outlined in the Food and Agriculture Organization (FAO) documents. Consequently, the governance of global food security can be seen as a facilitator of debates, promoting a space for interactions and confluence of ideas, as well as the planning and execution of actions in favor of improvements at the global level (FAO 2021b).

Another issue to be addressed is related to sustainable agriculture. According to the FAO website, "to be sustainable, agriculture must meet the needs of present and future generations, while ensuring profitability, environmental health and social and economic equity". Thus, by including actions to improve and foster sustainable agriculture, we will be contributing both to the pillars of food security (availability, access, use and stability), as well as to the pillars of sustainability (environmental, social and economical) (FAO 2021a).

According to the research by the authors Tittonell et al. (2021), there are more than 16 million family farms in Latin America, with 56% of these lands located in South America and 35% in Mexican territory, as well as in regions of Central America. Thus, the role of governance in these locations, as well as anywhere else in the world, needs greater attention and commitment.

In this context, the following hypothesis emerges: in order to fulfill the goals of the Sustainable Development Goals, with regard to more sustainable agriculture and food security, the role of governance in the Latin American territory needs to be urgently strengthened. Therefore, this chapter aims to address and contextualize the themes of Food Security (FS) and Sustainable Agriculture (SA) in Latin America and the roles of Latin American governance, as well as the relationship between FS and SA with the SDGs.

2 Methods

For the elaboration of this chapter, an integrative literature review was carried out. The objective was to compile studies on the role of governance in locations in Latin America, referring to Sustainable Agriculture and Food Security, as well as to carry out a discussion about the fulfillment of the goals of the SDGs.

An integrative review was chosen, so that an analysis method could be used that would bring together scientific literature and secondary documents from official organizations, such as reports and on-site data. According to Whittemore (2005), integrative review "allows us to understand a given phenomenon", as well as, according

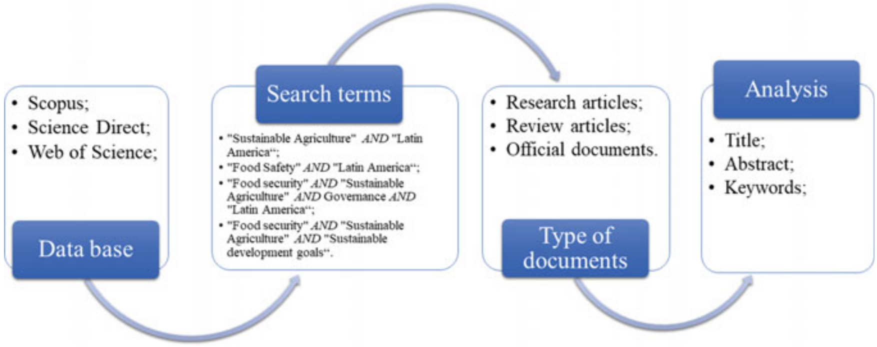


Fig. 1 Method used for the selection and analysis of articles. *Source* the authors or representative infographic of the method used for the selection and analysis of articles

to Torraco (2016) it is possible to review, criticize and synthesize representative literature on a specific topic and, thus, new data can be generated.

The selected databases were: Scopus, ScienceDirect and Proquest, and encompassing the analyzes of the documents of the Inter-American Development Bank, Food and Agriculture Organization (FAO) and the Sustainable Development Goals (SDGs). For the compilation of scientific literature, 4 combinations of search terms were used to write the sub-items. Figure 1 demonstrates the method used to select documents.

As shown in Fig. 1, to select the studies consistent with the theme proposed in this chapter, in addition to the search terms, filters such as the time frame and the type of documents were used. Then, the inclusion and exclusion criteria were applied (reading the title, abstract and keywords). Complementary documents such as "official documents" have contributed to fortifying the dialogue between scientific research and current data from government organizations.

Therefore, the results and discussions of this review article are structured as follows:

(a) "3. Analysis of scientific articles": analysis of the results regarding the number of studies found in the databases and their distribution in each sub-item.
(b) "3.1 Relationship and impacts of sustainable agriculture on food security in Latin America" compilation of researched studies on Sustainable Agriculture (SA) in Latin America. The objective here is to understand in a general way how aspects of SA are developed in the Latin American territory;
(c) "3.2 Latin American food security context": compilation of researched studies on Food Security (FS) in Latin America. The objective here is to understand in a general way how aspects of SF are developed in the Latin American territory;
(d) "3.3 Sustainable agriculture, food security and the role of governance in Latin American countries": compilation of research on Governance in Latin America and its role in sustainable agriculture (SA) and food security (FS). The objective

here is to understand in general how governance aspects are developed in the Latin American territory, using some countries as an example;

(e) "3.4 Sustainable Development Goals: the relationship of sustainable agriculture and food security in meeting the targets": compilation of researched studies on sustainable agriculture (SA) and food security (FS) related to the SDGs. The purpose here is to analyze how the SDGs can relate to the SA and FS aspects to meet your goals.

3 Analysis of Scientific Articles

Through the 4 sets of terms used and the filters "document type" and "time cut", 81 results were obtained in the Scopus database, 1301 results in the ScienceDirect database and 88 results in the Web of Science database. Table 1 shows the results of the research in this first step**.**

According to Table 1, the total was 1560 articles from 3 databases. Referring to step 1, after using the search filters, the inclusion and exclusion process was carried out by reading the title, abstract and keywords of each article. Thus, 1430 publications were excluded, as they were not consistent with the theme proposed by this chapter. Therefore, 130 articles selected in full were read. Regarding step 2, through the complete reading of the documents, 85 articles that were not in line with the scope of this review were excluded, highlighting the elimination of 20 articles due to repetition between the databases ScienceDirect, Web of Science and Scopus. With a total of 25 articles found in the literature, Fig. 2 shows the number of articles used to write each topic.

With a total of 25 articles, it is highlighted that a number of documents could be used in more than one topic for discussion, thus showing the important correlation between the topics covered. Consequently, it can be observed that the subjects that most used the articles found in the databases were "3.2. Latin American food security context" and "3.4 Sustainable Development Goals: the relationship of sustainable agriculture and food security in meeting the targets". This result shows the importance

Table 1 Search results in databases using filters

Search terms	Scopus	ScienceDirect	Web of science
"Sustainable agriculture" *AND* "Latin America"	16	382	17
"Food safety" *AND* "Latin America"	26	444	24
"Food security" *AND* "sustainable agriculture" *AND* Governance *AND* "Latin America"	1	95	0
"Food security" *AND* "sustainable agriculture" *AND* "sustainable development goals"	41	470	47
Total	81	1.391	88

Source The authors

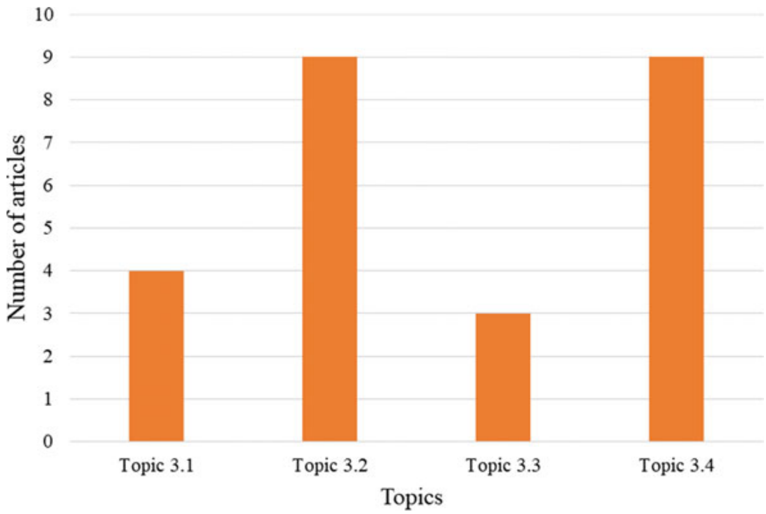


Fig. 2 Number of articles used for chapter writing. *Source* The authors

of deepening the discussion about food security, linked to the role of sustainable agriculture and is consistent with the purpose of the research that focuses on addressing the role of governance and alignment with the SDGs.

3.1 Relationship and Impacts of Sustainable Agriculture on Food Security in Latin America

Conceptualizing and defining sustainable agriculture is indeed a challenge, considering the daily demand for food for billions of people and the need for large-scale crops cultivation in contrast to predatory agriculture. In this connection, the best way to present sustainable agriculture is through the processes that best describe it, such as growing crops for the to preserve the soil, water resources, plant and animal genetics, using effective and economically and socially viable methods. Therefore, any interconnected agrifood system has to be transformed and should encompass multiple agricultural approaches, such as rotation and organic agriculture, which value the soil preservation and the like (Slimi et al. 2021).

There are reports that point out two main challenges for achieving sustainable agriculture, namely the misuse of natural resources and environmental degradation and, if sustainable agriculture were widely disseminated and developed, it would help to face the impacts of climate change and, consequently, would alleviate the exploitation of current natural resources or preserve them for the enjoyment of future generations (Torres Kallas and Herrera 2020).

Fig. 3 Major challenges for small farmers. *Source* Authors 2021

With regard to agriculture in Latin America, it is important to set apart large and medium-sized producers—large producers characterized by minor diversification in large territorial areas, more technology and management specialization—and the small producers with a high degree of crop diversification, yet, with a low degree of specialization, besides being composed mainly by family members (Pegorare et al. 2017). Figure 3 shows the biggest challenges for small agricultural producers.

Failure to adopt new technologies is directly associated with the lack of access to specialization and instruction; thus, large producers with access to advanced technologies for irrigation, spraying, pest control and disaster prevention, tend to recover more easily, produce on a large scale, reach a larger audience, export and import. In view of the greater vulnerability of small producers, their quest for development and improvements is driven by associations and cooperatives that seek government subsidies to aid production, in addition to incentives in the purchase of goods from local producers adding value to products, for example, through the obtention of stamps, certificates and productive practices based on environmental, social, and health criteria (Pegorare et al. 2017).

A study by Cervantes-Zapana and collaborators (2020), pointed out the economic, social and environmental benefits of family farming, especially when it is invested. With regard to the economic benefits, there is an increase in producers' incomes, in addition to stimulating the economy thanks to the purchasing power followed by price support acting as a price stabilizer, and inclusion in the market, which offers protection against price fluctuations and long-term planning capacity. With regard to the social sphere, transparency stands out since the consumer has easier access to information about the producer and its production processes; social capital through local collaboration, mutuality and cooperative processing and food security through the association of projects that include food derived from family farming in school meals and basic food baskets, guaranteeing access to nutritionally acceptable foods. In the environmental field, there is greater organic production, reduced CO_2 production and the diversification of low-scale conventional plant foods is characterized by an enormous diversity of domesticated crops (Cervantes-Zapana et al. 2020). Therefore, it is a bold statement to say that smallholder agriculture is closer to sustainability.

Regarding the importance of creating projects that support rural development, data from the Inter-American Development Bank (IDB) indicate 18 projects already carried out and underway in Latin America, Fig. 4 shows the division of Latin American countries that approved the greatest number of projects that involve agriculture and rural development.

Out of the 18 projects, nine deal with agricultural health and food security, two address the adhesion of agricultural technology and more sustainable agriculture development, while the rest of the projects are directed to soil management and to farm management, agriculture and rural development, agricultural industry, research and agricultural innovation, irrigation and drainage. These projects generated approximately US$ 964.33 million. Paraguay is the Latin American country that developed

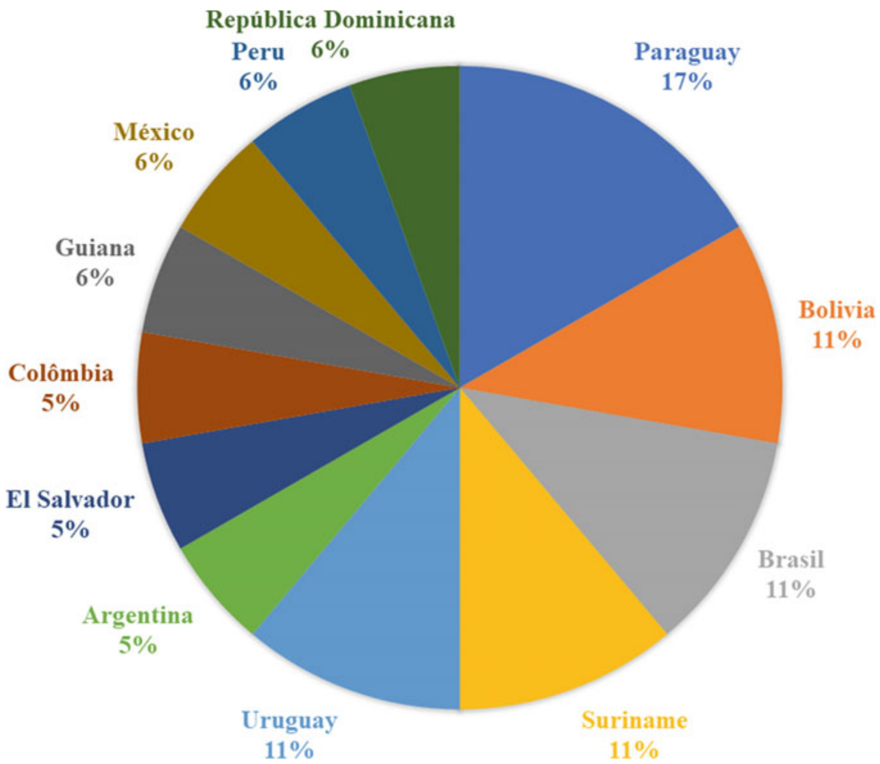


Fig. 4 Projects carried out and in progress in Latin America that involve agriculture and rural development. *Source* Data from the Inter-American Development Bank

most these projects, having implemented three, followed by Bolivia, Brazil, Suriname and Uruguay that developed two projects each.

Commonly, one of the most discussed unsustainable problems is the use of chemical agents to control crop pests. The uncontrolled use of insecticides generates impacts that are often irreversible on the environment, mainly due to the accumulation in soil, water, in the food itself, in the air and on the farmers' body when they spread these pesticides without the appropriate safety equipment (Struelen and Silva).

In addition to the unrestrained use of pesticides, Latin America faces challenges with regard to the equal division of land and its proper use, since it is the region that has the largest area of tropical forest in the world, where the greatest biodiversity is concentrated, which guarantees the global carbon stock, but face threats due to deforestation and uncontrolled agricultural expansion. Data show that Argentina, Brazil, Paraguay and Bolivia were responsible for 80% of deforestation across Latin America, in which 52% of the original Cerrado area was converted to pasture and agriculture. Being entirely connected to fires, which have been widely used to open new agricultural areas in Latin America, destroying soils, exposing them to erosion and leaching, besides smoke being a contributor to the release of greenhouse gases (Pegorare et al. 2017).

In this connection, the agenda extensively used in the discussions is the correlation between agriculture and climate change and the way in which they interact in connection with the relationship between population and economic advancement. Since they are interdependent, like a cycle, when something is out of balance, everything else is impacted. Therefore, there is a need to establish procedures to adjust production in agrarian structures or to alleviate the consequences of climate change on agriculture; it is extremely important that these strategies are implemented according to the characteristics of each region and rural workers (Torres et al. 2020).

It is essential to affirm that actions to improve the fight against climate change are emerging to ensure that agriculture and food security are not negatively impacted over the years Like these strategies, there is the adoption of no-till planting methods, organic agriculture, crop rotation, reforestation, organic fertilization, and land preservation actions as decrease in soil and rock deterioration, to consequently create picks up in nourishment efficiency (Torres et al. 2020).

A study by Torres et al. (2020) indicated actions in traditional agriculture that can minimize and eliminate the consequences of climate change. As an example, they suggested the adoption of more efficient machines to reduce fuel oil consumption and, consequently, reduce production costs and reduce the release of polluting gases. They highlighted the importance of increasing investment in irrigation infrastructure to optimize the use of water, in addition to generating increased productivity and harvest quality, crop rotation to increase productivity, reduction in the use of agrochemicals, thus reducing costs. The authors also report how the use of renewable energy is paramount in combating climate change. However, it is known that the access restrictions to these means, besides the low education of farmers, are limiting factors. In addition, farmers often seek technologies that provide them with a perceived benefit in the short term at farm level (Torres et al. 2020).

3.2 Latin American Food Security Context

Schleifer et al. (2020) elucidate that according to the United Nations, one of the most coherent meanings about food security is that “all people, at all times, have physical and economical access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life. Alarming data show that globally, approximately 821 million people are malnourished and 4 billion lack adequate nutrients or are overweight, despite the vast agricultural land area (Veldhuizen et al. 2020).

When it comes to food security, to determine its main definition, four main dimensions are available, represented in Fig. 5.

When people are subject to food insecurity, it means that there are periods of no availability of food, with negative impacts on their nutritional status. Therefore, adverse climatic conditions that disrupt crops, or subsistence crops production, directly impact the final price for the consumer or the producer runs out of nutritionally balanced food to consume. Variables such as political and financial precariousness affect food fragility, since as a result, many people become unemployed, unable to pay a higher price for healthy foods, often opting for foods rich in carbohydrates as an energy source (Schleifer and Sun 2020).

In economic terms, food security problems are entangled in production chains established as dominators based on global financial exchange. These imposing business model issues are clarified in part by the impacts of globalization, and there is a shift in genetically modified crops based on international patent systems (Rashmi and Rao 2010). Broadly speaking, it is conceivable to see a persistent confrontation between trade liberalization and safer, more sustainable and local food.

Therefore, the recurrent poverty from lack of employment or precarious work is a primary cause of hunger. Consequently, the need arises for policies to improve

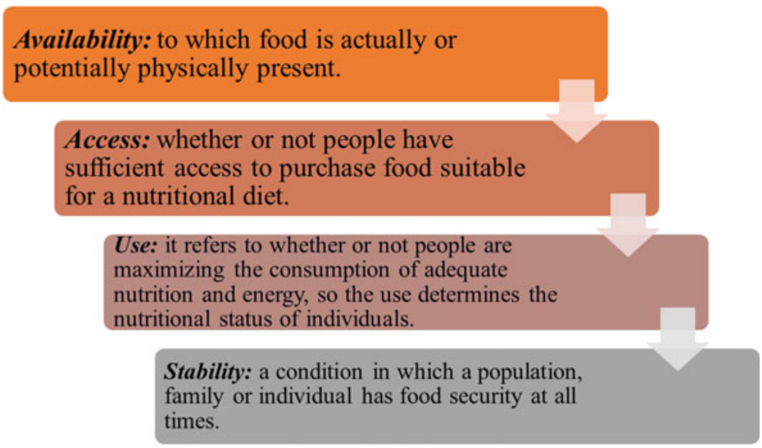


Fig. 5 The four main dimensions of food security. *Source* Authors 2021

economic access to ensure adequate food, with actions that involve social protection to boost progress in food and nutritional security, besides helping people who live in situations of greater vulnerability. Likewise, offering funds for family cultivation, as it is the essential source of income and survival for countless families, and the promotion of nutritious food and economic access for the rural population (FAO 2020).

3.3 Sustainable Agriculture, Food Security and the Role of Governance in Latin American Countries

The governance concept is a widely discussed subject due to its complexities. The currents of thought are diverse; the predominant discourses fluctuate and, consequently, so do the governments. Researchers, when carrying out the exercise of reflection on the data from the governance narratives in relation to issues such as poverty, hunger and social disparity, find a contradiction in discourses, as they end up involving opposing ideological currents. (Kepple and Segall-Corrêa 2017; Jiren et al. 2020).

These global discourses on food security governance, for example, may encompass a neoliberal approach, which advocates modernization and industrialization of agriculture, while the focus on food and its adversities are part of an alternative discourse to food security that prioritizes regional agroecological production. of food through sustainable agriculture (Jiren et al. 2020). It is emphasized that climate changes undermine sustainable agricultural development and have profound impacts on the pillars of sustainability, especially in developing countries, where agriculture is one of the main sources of survival. (Torres et al. 2020).

According to Torres et al. (2020), agricultural production and food security will be compromised in the long term, if effective mitigation practices in relation to climate change do not occur. One solution pointed out by the authors is the no-tillage technique, as it reduces soil degradation and, consequently, increases productivity and profits.

In this way, governance issues along with food issues and more sustainable agriculture remain a major concern for policy makers at all levels, and remain a major concern for policy makers at all levels. According to Pérez-Escamilla et al. (2017), it is important and necessary to recognize and verify food insecurity (FI) indicators, "as they are useful for policy makers to improve their targeting and monitoring efforts".

It is noteworthy that these issues and concerns were aggravated due to the current pandemic context. According to the studies by Tittonell et al. (2021), restrictions on the international mobility of goods and people due to the COVID-19 pandemic context, damaged the food system in the world, especially with regard to access to food, due to the fact that a country is tied to and often dependent on other.

As an example, the closure of entertainment and tourism venues, which meant an abrupt reduction in demand, can be mentioned; the avoidance of consumers during the pandemic resulting in staying away from fairs and markets nearby, which are often attended by small and medium-sized family farmers; and, it also includes the fact that hundreds of thousands of children have been left without a basic food and nutritional intake due to the stoppage of educational institutions (Tittonell et al. 2021).

There are more than 16 million family farms in Latin America, with 56% of these lands located in South America and 35% in Mexican territory, as well as in regions of Central America (Tittonell et al. 2021). Therefore, the role of governance in these locations, as well as anywhere else in the world, requires greater attention and commitment. The role of governance linked to food security encompasses several social, environmental and economic aspects, thus becoming a commitment that requires extreme responsibility and coherence (Pérez-Escamilla et al. 2017). According to the studies by Pérez-Escamilla et al. (2017), these factors are interconnected and can be seen in Fig. 6.

According to this paper's authors, the above factors that moved the role of governance in relation to food security have gained prominence in research in recent years. Therefore, one must take into account the various existing points such as "government activities and products and the results of the policies involved in feeding the population" (Pérez-Escamilla et al. 2017). For Berchin et al. (2019) and Kepple and Segall-Corrêa (2017), the role of governance on food security, goes beyond the way society is managed in relation to the three pillars of food security: the availability,

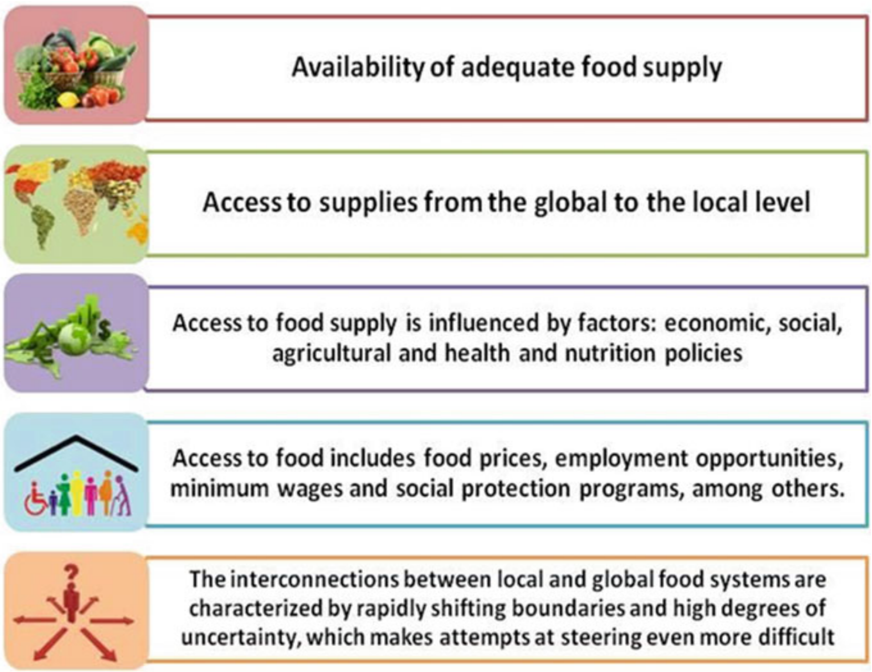


Fig. 6 Factors that operate in different aspects of the socioecological pattern. *Source* The authors

access and use of food. This includes how the government positions itself and carries out its decision-making in accordance with the reality and rights of the population.

Not just in Latin America, but in all developing countries, family farming with its strong connection to food security provides food, raw materials and jobs in the rural region.. We must also emphasize that the preservation of biodiversity and agriculture can come through the maintenance and enhancement of the rural food production process. Consequently, these actions contribute to the role of governance regarding natural resources (Tittonell et al. 2021; Torres et al. 2020).

It is important to remember that in 1980 the Latin American governments went through a strong economic crisis and, from the 1990s onwards, they carried out economic reforms. These reforms were extremely important, as through them it was possible to achieve economic consolidation in the medium term, thus bringing about improvements in the social, infrastructure, educational and governance spheres. (Vargas-Lama et al. 2020).

According to research by Mahlknecht et al. (2020), in a broad sense, sustainable development has perspectives that focus on agriculture in Latin America and the Caribbean, thinking about food security, the associated environmental choices such as the concern with the water footprint, carbon footprint, quality of water, and impacts on biodiversity.

According to malnutrition estimates, in the Latin American and Caribbean region, there was a drop in the number of people facing hunger from 14.7% between 1990 and 1992 to 5.5% between 2014 and 2016. However, there are still more than 34 million malnourished people, with a considerable difference in regions of Mexico ($\cong$ 4%), South America ($\cong$ 5%), Central America ($\cong$ 13%) and the Caribbean ($\cong$ 20%). These data show a sluggishness in terms of the reduction of malnutrition in Central America and the Caribbean, even highlighting a worsening due to natural disasters and economic difficulties in some countries in the last 15 years (Mahlknecht et al. 2020).

In Mexico, for example, some worrying data were collected, bringing to light the reality that more than 13% of children under the age of five suffer from chronic malnutrition and approximately 35,000 children have died due to malnutrition; more than 45% of Mexicans survive on the poverty line, and approximately half of these people experience the condition of food insecurity (Shamah-Levy et al. 2017).

With respect to nourishment accessibility, Mexico offers a day by day supply of dietary vitality of 3141 kcal per capita. It should also be noted that the Mexican rural structure organized and introduced 25 years ago has not changed since then, with corn still being Mexico's staple food (Shamah-Levy et al. 2017). During the period from 1940 to 1965, a boom in agricultural production exceeded the population's consumption and caused "the golden age of agricultural growth" making the agricultural sector a central feature of the Mexican economy and sovereignty (Galeana-Pizaña et al. 2021).

However, nowadays, it can be said that the agrarian structure of Mexico is uneven, as the agrarian and productive structure is concentrated in a small group of capitalized producers who were able to invest in its modernization, however, there is a large majority of small producers agrarians who live in precarious regions and with few conditions to improve their production (Shamah-Levy et al. 2017). In 2016, it was found that approximately 79% of Mexico's rural population had somehow experienced food insecurity and, after two years, around 20% of the Mexican rural population did not have enough income to buy basic foodstuffs (Galeana-Pizaña et al. 2021).

In 2010, the government implemented the *Acordo Nacional para a Nutrição Saudável* (ANSA, National Agreement for Healthy Nutrition), joining forces between the government, the food industry and universities It formulated ten goals that aim to achieve healthy eating, an active lifestyle among Mexicans and defined a political approach to direct business and food transport in schools (Shamah-Levy et al. 2017). The National Campaign Against Starvation (2013), known as the "National Crusade against Hunger", promoted by the Ministry of Social Development, aimed to eliminate poverty in its vast majority, the precarious health and food conditions resulting from food inaccessibility in Mexico (Galeana-Pizaña et al. 2021; Shamah-Levy et al. 2017).

For scholars Shamah-Levy et al. (2017), Mexico needs a consistent and effective food governance plan to ensure nutritious food for the population. For this to happen, it is essential to reassess public policies and programs that fight food insecurity and implement lasting measures.

Galeana-Pizaña et al. (2021) through "Structural Equation Modeling", suggested a conceptual model aimed at issues related to food security of the Mexican rural population so that the occurrence of family farming in relation to commercial farming could be discussed. According to the authors, regarding food security, of the 81 rural affiliations, 52 resulted from family farming and 29 resulted from modern agriculture. Thus, a closer relationship was observed between family farming and rural food security than between modern agriculture and food security In Brazil, for example, governance practices have shown that circumstances around food security can be improved by taking three essential actions, namely, the elaboration of a current public policy program, the foundation of a service especially for the organization and management of the work of other ministries to achieve food security targets and the incorporation of partners within the decision-making sphere (Shamah-Levy et al. 2017).

According to the studies by Berchin et al. (2019), family farming has an immense representation in terms of world agricultural structures. When it comes to growing spaces, farm sizes range from 1 ha to 10,000 ha. In Brazil, for example, the size of farms can go from 0.5 ha in the south of Brazil to 100 ha in the north, reaching an estimated 18 ha, due to state guidelines.

Brazilian data show that family farming is compared to approximately 4.4 million properties, comprising approximately 12.3 million people in rural work in the country and covering about 80.10 million ha of all Brazilian agrarian units, thus highlighting the efficiency of family farming in the country, especially in southern Brazil (Berchin et al. 2019).

After the Brazilian military government, in the 1980s, large social groups developed that promoted and encouraged agrarian reform and, consequently, resulted in significant changes in public policies such as the achievement of rights and egalitarian and dignified living conditions. Since 1990, national public policies have been created especially to serve family farmers through programs and incentives, as mentioned by the authors Berchin et al. (2019), the National Program for Strengthening Family Farming (PRONAF), Family Farming Insurance (SEAF), Family Farming Price Guarantee Program (PFPAF) and Crop Guarantee Program.

The national program “Zero Hunger”, created in 2004, from the adhesion of the so-called “Brazilian Scale of Food Insecurity” (EBIA—original acronym), provided an assessment and measurement of the food insecurity experience of rural and urban households. There are many cases of investments in family farming and Brazilian food security. According to information from the Central Bank of Brazil, between 2014 and 2017, there was a significant reduction in the number of contracts and in the amount of appropriations paid by the government in programs such as Pronaf. Subsequently, he observed that agribusiness in Brazil, to put up with adversity in relation to social, political, financial and environmental spheres. (Berchin et al. 2019; Kepple and Segall-Corrêa 2017).

School feeding was the focus of a study in Brazil by researchers from Brazil and the United Kingdom in 2014, in order to verify the governance of food safety. Based on the legislation and policy documents, it was possible to gain two insights: (a) the importance of expanding interest in the sphere of governance to populations that have been neglected when it comes to food security; and (b) the need to move towards social learning was emphasized, not only for the role of governance, but above all for the communities, thus ensuring possible and coherent practices, increasingly reducing inequality and food insecurity (Sonnino et al. 2014).

Finally, these were a few examples of studies that reported the situations regarding food security and more sustainable cultivation in the countries of Latin America, showing some general data and, quoting as cases, Mexico and Brazil. It is noticeable the needs and delays of these regions and the difference that competent governance makes in the life of millions of people who try to survive in these developing countries. Thus, observing the complexities surrounding the subject, the investment in public policies and an efficient government, makes a difference in challenging food insecurity and in the development of sustainable agriculture.

3.4 Sustainable Development Goals: The Relationship of Sustainable Agriculture and Food Security in Meeting the Targets

Food security and sustainable agriculture are important components of the Sustainable Development Goals (SDGs) and can be observed in their main scope, through SDG 1 “Eradication of poverty” and SDG 2 “Zero hunger and sustainable agriculture”. As regards the Agenda 2030, SDG 1 is composed of 7 goals and aims to eradicate poverty in all forms and in all places, while SDG 2 is composed of 8 goals and points to annihilate starvation, accomplish more nutritious food security and promote sustainable agriculture (UNDP 2015).

For Sarkar et al. (2020), one of the challenges related to global sustainability is characterized by enhancing the generation of nutrients to feed a society in rapid development and, at the same time, reducing the use of natural resources and soil deterioration. Thus, more sustainable cultivation practices based on a low source of inputs are essential to reduce environmental trade-offs and the generation of nutritious food, according to the SDGs.

In addition to SDGs 1 and 2, the other objectives of the 2030 Agenda can also address these issues indirectly, focusing on socioeconomic factors: health and well-being, education, gender equality, accessibility of resources, work, responsible consumption and production, deterioration of soil, among others. Thus, at a global level, it is perceived that the dialogue between public policies and agriculture is essential for the eradication of hunger (Berchin et al. 2019). Figure 7, makes this relationship between the pillars of sustainability and the Sustainable Development Goals.

Broadly speaking, when thinking about the social, economic and environmental factors that make up the pillars of sustainability related to the SDGs, the interconnections and the relevance of ensuring safe food and sustainability in agriculture in favor of sustainable development. For, so that the population in a situation of vulnerability can be part of the construction of an environmentally, socially and economically ethical system, it is necessary, first, that these people have access to what is basic: nutritious and safe food.

Between 1990 and 2014, Latin America and the Caribbean reduced its malnourished population statistics by 60%, reaching the goal of halving the rate of people

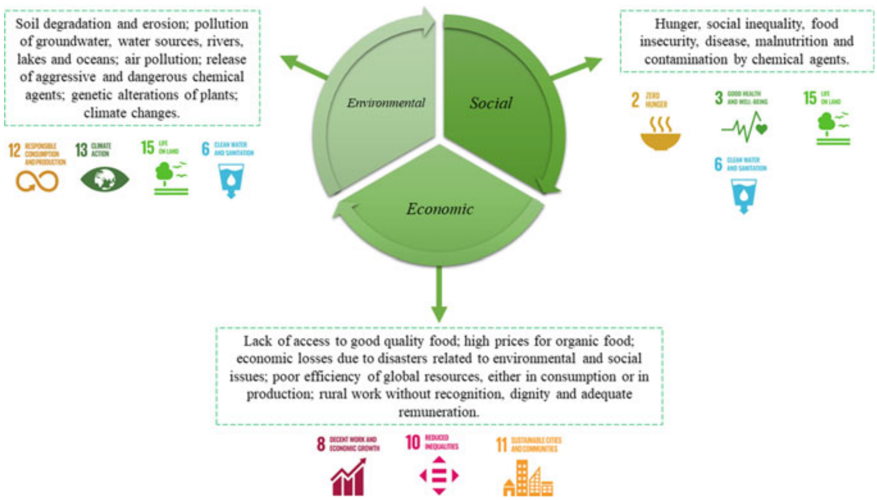


Fig. 7 Relationship of the sustainability pillars with the sustainable development goals *Source* The authors

experiencing hunger, according to data from the Food and Agriculture Organization (FAO). The experience of the locals reveals that, in order to social obstacles, specifically the population that suffers from hunger and finds itself in the line of extreme poverty, it is necessary to combine economic growth with a commitment to effective political actions that manifest themselves in the unfolding of various policies high impact public services in the most vulnerable populations (FAO 2021a, b).

According to Pérez-Escamilla et al. (2017), for the realization of each of the SDGs, the role of governance in relation to food safety should be seen as one of the central issues. SDG 2 aims to eradicate hunger, while the other goals aim to take care of social and economic components that are essential to combat food insecurity, promote health and environmental preservation.

Table 2 lists the SDGs in relation to food insecurity and sustainable agriculture.

Table 2 shows the importance of the search for the improvement of more effective practices for food security and sustainable agriculture is evident, since it is possible to relate this subject to the Sustainable Development Goals. As previously stated, SDGs 1 and 2 cover food security and sustainable agriculture more directly; however, indirect issues such as gender, partnerships between developed and developing countries, education, technological innovations, among others, are important and cannot be forgotten.

As an example are the studies by Agarwal (2018). The researcher examined the capacity and limitations of SDG 5 in order to contribute to and effect safer family nutrition. According to the author, stimulating and maximizing women's access to agricultural practices increases the capacity for food production. However, there are some limitations related to the restrictions that women farmers face as to which natural resources can be accessed and the non-recognition of the potential of forests and fisheries as food sources.

In addition, the author points out other objectives associated to food security as important nutrition providers and that require further studies, such as SDG 15 with regard to forests and SDG 14 with regard to fisheries resources, as they do not mention gender equality and neither SDG 13 (climate action) recognizes the vulnerabilities of women farmers (Agarwal 2018).

Finally, according to Tanumihardjo et al. (2020), complying with SDG 1, the other goals will be achieved with greater effectiveness, as if the entire population, especially people in vulnerable conditions, obtain a decent income, consequently the other stages such as safe food, access to health, among others, it will be a reality. The authors also cite as an example that when the income of people living in the extreme poverty line increases, food is their first spending option and, consequently, contributes to eliminating hunger, lack of food nutrients and food insecurity.

4 Conclusion

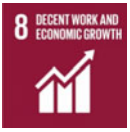
It was observed that the concept of governance is a complex issue due to different currents of thought. However, there is a clear need to understand the role of governance in relation to safer food and more sustainable cultivation in territories globally. It was also found that improving governance in favor of safe eating significantly

Table 2 Relationship of SDGs with food insecurity and sustainable agriculture

Goals	Featured Target	Relationship with food insecurity and sustainable agriculture
	−1.1 eradicate extreme poverty worldwide, who currently survive on less than $1.25 a day; −1.4 ensures that all people, especially the vulnerable population, have their guaranteed and equal rights related to economic resources, basic services, autonomy over their ownership, access to new technologies and financial services	−Poverty is one of the main determinants and consequences of food insecurity; −Economic resources guarantee population access to food and control over land can enable food production as a means of subsistence
	−2.1 eliminate hunger and guarantee access to basic services and nutritious food for the entire population, essentially people in a vulnerable condition −2.3 increase the production and earnings of small farmers and other rural workers, with a special focus on women, indigenous people, and fishermen, with equal access to land, production and inputs, information, financial services, non-rural jobs, among others; −2.4 ensures more sustainable and resilient agricultural production, with an increase in demand, and at the same time, preserve ecosystems, contributing to the fight against climate change	−The SDG contributes directly to the end of food insecurity; −The SDG contributes directly to a more sustainable production, mainly thinking about small producers, family farming, indigenous peoples, among others
	−3.9 significantly reduces the number of deaths and illnesses caused by hazardous chemicals, contamination of the natural environment −3.d Consolidate the capacity of countries, especially developing countries, for procedures in relation to risk reduction and management and health and well-being	−Food insecurity has been associated with physical and mental health problems throughout the course of life; −Sustainable agriculture is concerned with the entire productive, environmental, social and economic process

(continued)

Table 2 (continued)

Goals	Featured Target	Relationship with food insecurity and sustainable agriculture
	−4.7 guarantee that all students can have access to information and how to proceed in relation to sustainable development, through environmental education, human rights, gender equality, culture of peace, citizenship and the appreciation and respect for cultural diversity	−Food insecurity affects children's ability to learn at school; −Sustainable agriculture contributes to organic, safe and nutritious food; −Children, youth and adults have the right to access knowledge about sustainable development and how these issues can contribute to their lives
	−5. to uphold the equal rights of women regarding economic resources, access and autonomy to property, financial services in accordance with local legislation	−Encourage food security among women and girls, focusing on health and education.; −Empower and encourage women farmers, indigenous people, among others, aiming at sustainable development and autonomy
	−6.2 ensure adequate basic sanitation and hygiene for the entire population, with special attention to women and girls in vulnerable situations; −6.3 ensure access to quality water, combat pollution, and waste substantially increasing recycling and safe reuse	−The reduction of infectious diseases through improved hygiene and sanitation reduces food insecurity, as families have more disposable income for food; −Through sustainable agriculture it is possible to eliminate the use of pesticides, thus protecting water resources, as well as thinking about mechanisms for water reuse
	−7.1 ensure universal, reliable, modern and affordable access to energy services; −7.2 substantially increase the share of renewable energies in the global energy matrix	−Access to electricity improves food availability and access to food at home; −Access to electricity, giving priority to renewable energy, contributes to the work of many farmers and producers in their crops and machinery in favor of sustainability
	−8.4 to increase the efficiency of resources in consumption and production worldwide, and to decouple economic development from environmental deterioration in accordance with the Ten-Year Plan for Sustainable Production and Consumption Programs −8.5 that the entire population can have equal access to full, lucrative employment and decent working conditions	−Sustainable agriculture helps to decouple economic growth from environmental degradation, promoting investments in more sustainable technologies and habits in production and consumption; −Socioeconomic inequities are the root cause of food insecurity. Unemployment is one of the main social determinants, leads to less productivity and, therefore, impedes sustainable economic growth

(continued)

Table 2 (continued)

Goals	Featured Target	Relationship with food insecurity and sustainable agriculture
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	–9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and cross-border infrastructure, to support economic development and equal well-being for the entire population	–Socioeconomic inequities are the root cause of food insecurity and are likely to lead to less innovation, preventing sustainable innovation; –With support for sustainable and economic development, sustainable agriculture can be a reality for many countries, especially developing countries
10 REDUCED INEQUALITIES	–10.2 foster social, economic and political inclusion for people equally, regardless of their beliefs, social class, gender, ethnicity, among others	–Socioeconomic inequities are the root cause of food insecurity; –With social inclusion and incentives for education and work, countless families will be able to use sustainable agriculture as a source of income
11 SUSTAINABLE CITIES AND COMMUNITIES	–11.1 ensure access for all to safe, adequate housing, access to basic services and the urbanization of vulnerable communities; –11.a strengthen healthy socio-economic and environmental links between urban and rural areas, among others, reinforcing national and regional development planning	–The lack of housing security is a strong determinant of food insecurity; –Support and investment for urban and rural areas contributes to sustainable agriculture, as it favors both sustainable production and conscious consumption
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	–12.3 Significantly reduce the loss and disuse of food globally, in all sectors ("farm to fork") –12.8 ensure that the entire world population has information to raise awareness of sustainable development –12.a ensure that developing countries consolidate their scientific and technological skills so that they can promote more sustainable production and consumption in their communities	–Environmental sustainability reduces the risk of food insecurity and is associated with unsustainable agricultural practices and environmental degradation
13 CLIMATE ACTION	–13.1 Strengthen resilience and the ability to adapt to risks related to climate and natural disasters in all countries; –13.b Promote effective training methods for combating climate change and management in less developed countries, prioritizing women, young people and communities in situations of vulnerability	–Environmental degradation due to climate change increases the risk of food insecurity, harms the small producer and the entire sustainable agriculture system

(continued)

Table 2 (continued)

Goals	Featured Target	Relationship with food insecurity and sustainable agriculture
14 LIFE BELOW WATER	−14.1 conservation and sustainable use of the marine ecosystem and its surroundings for sustainable development; −14.7 maximize the economic resources of small island developing countries and other less developed localities, employing more sustainable management of marine resources through fisheries, aquaculture and tourism; −14.b provide artisanal fishermen with access to marine resources	−The sustainability of marine ecosystems reduces the risk of widespread food insecurity
15 LIFE ON LAND	−15.1 ensure the sustainable use of land and freshwater resources in accordance with international pacts; −15.9 value ecosystems and biodiversity in the planning of all territories, in favor of a more sustainable development encompassing all economic, social and environmental pillars	−maintenance capacity of terrestrial biological systems reduces the risk of long-range food fragility and contributes to the achievement of sustainable cultivation
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	−16.1 effectively reduce all forms of violence and the percentage of mortality in all regions; −16.5 significantly reduce corruption and bribery in all social, economic and environmental spheres; −16.8 consolidate and maximize the participation of developing countries in the role of global governance	−Conflict is a risk factor for food insecurity and to promote and encourage sustainable agriculture. Adequate global governance is necessary to prevent conflicts
17 PARTNERSHIPS FOR THE GOALS	−17.1 Consolidate the capacity of least developed countries to collect all forms of revenue; −17.16 Encourage a global partnership for sustainable development, sharing knowledge, experience, technology and economic resources, with a central focus on developing countries	−Sustainable global partnerships are needed to reduce food insecurity and to promote and encourage sustainable agriculture

Source The authors (Adapted from Pérez-Escamilla et al. 2017) depends on the identification and understanding of indicators of food insecurity (FI), a term raised by researchers in the field, which are useful for public policy makers.

Countries like Mexico and Brazil were cited as examples of localities in Latin America and, despite some efforts through government campaigns and programs, both have unequal characteristics in their socioeconomic aspects. Agriculture and production processes are concentrated in a small group of modern farmers and holders of high investments on the one hand, and on the other, a majority of small producers such as family farmers, who mostly live in precarious areas and conditions. Therefore, the needs that these regions have been experiencing and the difference that competent governance makes in the lives of millions of people trying to survive in these countries are noticeable. Therefore, investment in public policies and in an effective government makes a difference in the struggle against food insecurity and in the development for sustainable agriculture.

In relation to the Sustainable Development Goals, food security and sustainable agriculture are important components and can be observed in their main scope, through SDG 1 "Eradicating poverty" and SDG 2 "Zero hunger and sustainable agriculture". Efforts to achieve the SDGs by the 2030 target must be aligned with the food system, requiring investments in agronomic research and agricultural systems to improve food systems as a whole emphasizing nutritional aspects.

Its relationship with the other targets was also quite clear, as as stated by Tanumihardjo et al. (2020), when we meet the goal of "Eradicating Poverty", this goal will have extremely positive impacts for the other SDGs, since, when the population increases its earnings, people can focus on other issues such as nutritious food, health and sustainability.

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Sustainable Agriculture and Food Security in Qatar: International Threats and Local Constraints

Tarek Ben Hassen and Hamid El Bilali

Definitions

"Food security exists when all people at all times have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). Within the 2030 Agenda for Sustainable Development, Food security for all is considered a critical component of Sustainable Development Goal 2, 'Zero Hunger'. In the NENA (Near East and North Africa) area, food insecurity and malnutrition are significant issues. They can be accentuated by the projected dire climate change effects on agriculture and food systems in the region. However, there are huge dissimilarities between poor countries (e.g. Yemen, Somalia) and the wealthy Gulf Cooperation Council (GCC) states (Saudi Arabia, the United Arab Emirates, Oman, Kuwait, Qatar, and Bahrain). In this context, although Qatar has one of the highest food security levels in the NENA region, it faces several political, environmental, and socio-economic challenges in achieving its sustainable food security.

Sustainability and food security are amongst the most significant challenges facing the world today. Indeed, food system activities significantly impact food security dimensions (viz. availability, access, utilization, and stability). Resolving the multiple social, economic, and environmental challenges implies transforming the food system to increase nutritional outcomes while minimizing environmental impact, as well as moving to a sustainable food system. As defined by the High Level Panel of Experts on Food Security and Nutrition (HLPE 2014), "A sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such

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a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised" (p. 31).

The chapter deals with agriculture and food production in Qatar and analyses the current food strategies and measures to realize food and nutrition security. It analyzes drivers of changes, trends, challenges, and policy responses to ensure the country's food security. To achieve long-term food security in Qatar, the chapter advocates developing efficient and sustainable agriculture with high resource efficiency.

1 Introduction

Food security has been a continuing concern in Qatar since the global food crisis of 2007–2008, as its increasing population places considerable strain on the government (GSDP 2018). Indeed, food security is at the forefront of Qatar's development priorities and a fundamental pillar of the country's security, in accordance with Qatar's national vision 2030, which seeks to render Qatar a developed country able to achieve sustainable development by 2030 (GSDP 2008). Based on its financial strength, Qatar implemented two main policies: abroad acquisitions/investments and long-term food import arrangements (Ben Hassen and El Bilali 2019b). Its oil and gas resources have allowed it to maintain high food security by large food imports from the global markets (Hussein and Lambert 2020). Therefore, the Global Food Security Index placed Qatar 37th globally and third in the Arab world in 2020 (The Economist Intelligence Unit 2021).

Nevertheless, Qatar faces several political, environmental, and socio-economic challenges in achieving its sustainable food security. Firstly, Qatar remains a net food importer (Ben Hassen et al. 2020). Secondly, since most food imports pass through Hormuz Strait and the Saudi Arabia border, the region's geopolitical instability could threaten Qatar's food supply (Ben Hassen and El Bilali 2019b; Ismail 2015). Moreover, denied food supplies from the neighboring countries following the 2017 Gulf Rift showed Qatar's high dependence on imports and the need to raise local production (Hussein and Lambert 2020; Koch 2021). Since then, the Qatari government has taken several policies to diminish the impact of the Rift on food security and increase local production (Ben Hassen et al. 2020; Ben Hassen and El Bilali 2019b). However, as Qatar is situated in one of the world's driest regions, agricultural activities are constrained by several natural characteristics, such as limited freshwater resources, harsh climate, and unfertile soil (FAO 2008; Ismail 2015).

Additionally, agriculture is constrained by many structural issues such as inefficient water use and obsolete farming methods (GSDP 2011). As a result, there is a need to move to sustainable food systems that guarantee the twin ambitions of productivity and environmental sustainability (Capone et al. 2014; El Bilali et al. 2019). Indeed, agriculture should be productive and sustainable at the same time. In this context, new technologies, innovations, and research and development (R&D), suitable local natural conditions can be used, along with local and traditional knowledge, to improve the productivity and the sustainability of the local food production supported by efficient, holistic, and comprehensive policies (Brown et al. 2018; Hussein and El Harizi 2013).

The chapter deals with agriculture and food production characteristics in Qatar and analyses the current food policies and strategies to realize food and nutrition security in the country. It analyzes drivers of changes, trends, challenges, and policy responses to ensure the country's food security, especially to confront the effects of the 2017 Gulf Rift. Hence, the chapter is based on a main hypothesis stating that increasing local food production and its sustainability in Qatar needs policies that promote sustainable agriculture with high water and land use efficiency and the capacity to continuously innovate in technology, practices, and products.

This chapter combines scholarly literature (Scopus, Google Scholar) and grey literature (e.g. reports, books). Indeed, it includes a review of scholarly, peer-reviewed scientific literature dealing with agriculture and food security in Qatar from Scopus and Google Scholar databases. The used grey literature encompasses secondary data from reports, governmental documents, websites, and newspapers articles, from different sources, both domestic (e.g. Ministry of Municipality and Environment of Qatar, General Secretariat for Development Planning, Qatar National Human Rights Committee, Planning and Statistics Authority) and international (e.g. FAO, UNDP, IFPRI, RAND Corporation, Economist Intelligence Unit, World Bank, CIHEAM).

First, the chapter presents Qatar's socio-economic characteristics and how its food security represents a critical political issue and a significant ongoing challenge. Then, it presents the natural constraints (e.g. harsh climate, scarce soil and water resources) and structural challenges (e.g. scarce water resources and poor soils, low use of modern agricultural techniques) limiting local food production in Qatar. In Sect. 3, the chapter analyzes the limitations and drawbacks of import-based food policies (e.g. price risk and availability risk due to import disruption or export restrictions). It presents some strategies adopted by Qatar to manage price and supply risks following the 2007–2008 global food crisis, such as creating the Qatar National Food Security Program (QNFSP) and international investments. The chapter ends with analyzing the policy responses to ensure the country's food security to confront the effects of the 2017 Gulf Rift (e.g. establishing alternative trade routes, increasing local production, adopting a new food security strategy).

2 Food Security and Self-Sufficiency in Qatar: A Critical Political Issue

Qatar, one of the GCC countries, is a small and wealthy country, with a land area of 11,437 km^2 and a population of 2.723 million inhabitants as of September 2020 (Planning and Statistics Authority 2020). With 12.4% of the proven global gas reserves, Qatar ranks third behind Russia and Iran (British Petroleum 2020). These massive reserves have placed Qatar as the world's 5th biggest gas producer, second-largest gas exporter, and main liquefied natural gas (LNG) exporter (World Bank 2020). Subsequently, in 2019, with a Gross Domestic Product (GDP) per capita of US$ 65,137.6, Qatar is regarded as one of the world's richest nations (World Bank 2020). Qatar's economy is expanding steadily in tandem with the country's population increase (mainly expatriates). When it gained independence in 1971, Qatar had just over 100,000 inhabitants. From 1990 until 2020, the population rose from 476,278 to 2.723 million. Qatar's population is projected to grow by 40% by 2050 (World Population Review 2021). Indeed, the country has seen its population increase 30-fold over the past five decades and swell by two million since 2005. The government's economic and infrastructural development, especially since the mid-2000s supporting the FIFA 2022 World Cup preparations, has resulted in a demographic boom with a large influx of expatriates to Qatar. Today, only 15% of Qatar's inhabitants are "citizens", approximately 300,000 people (World Population Review 2021). From 1990 until 2020, the GDP increased from 7.36 billion $ to 192 billion $ for the same period (Planning and Statistics Authority 2020). These increases in GDP and population were coupled with expanding urbanization, rising income, and purchasing power (GSDP 2017), putting the country under pressure to meet the growing demands while also ensuring resource stability for future development, resulting in an imminent rise in overall food demand and an increasing sense of national food insecurity (Hussein and Lambert 2020). Hence, food security has become an ongoing challenge in Qatar.

However, while it has the third-largest natural gas reserves globally and shows many signs of wealth, Qatar lacks water, land, and climate to ensure its food security (Karanisa et al. 2021). Domestic food production has always been limited and primarily based on date farming, traditional fishing, and Bedouin animal husbandry. Since the 1970s, Qatar has depended largely on imported food to sustain its growing population, where wealthy households are becoming demanding on the quality and diversity of products. (Ben Hassen et al. 2020). The volume of annual agricultural and food purchases was 500,000 tons at the turn of the century. Imports now reach over 2.5 million tons. Imports continue to grow as the population grows and stands at USD 3 billion in 2018 (up from USD 1.5 billion in 2008), representing 10% of all Qatari purchases abroad (Fig. 1).

Like the other GCC nations, Qatar has traditionally used its important financial resources to purchase its food needs, making it more resistant to food price increases and uncertainty than other food-importing countries (Efron et al. 2018; Ismail 2015). As a result, Qatar ranks among the top globally regarding food security and, in particular, food affordability. Qatar was placed third in the Arab world and 37th internationally in the 2020 Global Food Security Index (The Economist Intelligence Unit 2021).

Despite this success, the country remains a net importer of essential food items, especially cereals, the primary staple foods (Alpen Capital 2019). Furthermore, food consumption in Qatar is forecast to rise from 1.7 million MT in 2018 to 1.9 million MT in 2023, at a 2.3% annual pace, led by population growth and significant and growing income (Alpen Capital 2019). Food consumption is also influenced by the increasing number of tourists visiting the country. The forthcoming FIFA World Cup in 2022 will draw 3.1 million visitors, up from 2.3 million in 2017 (MERatings 2019).

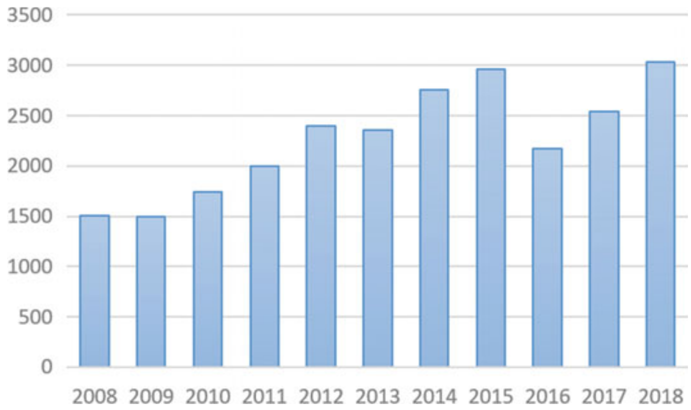

Fig. 1 Qatar's food imports value (billion US$) between 2008 and 2018. *Source* Authors' elaboration based on data from Embassy of France in Qatar (2020)

Qatar's heavy reliance on food imports exposes it to supply shocks, food price fluctuations, and trade restrictions. Therefore, the availability and stability dimensions of food security still represent real challenges (Namany et al. 2020). The 2017 Gulf Rift highlighted the low effectiveness of the current food policies and the high risks of Qatar's high dependence on food imports. How Qatar will face up food security in the future will strongly affect its prosperity, stability, and the quality of life of its growing population (The Economist Intelligence Unit 2010). Therefore, it is no surprise that food security is an integral part of national security for the Qatari government. The blockade of 2017 put achieving long-term, sustainable food security even higher on the agenda of the government and decision-makers in Qatar.

3 Food Production in Qatar: Natural Constraints and Structural Challenges

Qatar's path to food self-sufficiency is a daunting challenge. Since Qatar is a desert territory, the interconnected limited suitable lands and irrigation water are the major limitations for expanded local agricultural production, making Qatar dependent on food imports (FAO 2013). Indeed, Qatar is located in the northern hemisphere desert, and according to Köppen's classification, Qatar has a hot desert climate (BWh) (Kottek et al. 2006). These environmental factors pose significant challenges for agricultural development, and farming in Qatar has historically been restricted to the period from October to April (Karanisa et al. 2021). Consequently, with an annual average of about 75.2 mm for 1962–2015, Qatar's climate is arid with limited rainfall and high evapotranspiration (GSDP 2017). Precipitations are also unpredictable, making them unreliable for enhancing irrigation and sustaining agriculture (FAO 2008). In addition, Qatar's climate is characterized by high temperatures during

Table 1 Annual relative humidity and rainfall in Qatar (2015–2019)

Rainfall (in mm)	Relative humidity		Year
	Max.	Min.	
114.5	74	37	2015
101.1	66	25	2016
78.4	66	24	2017
119.9	63	22	2018
83.4	62	23	2019

Source Planning and Statistics Authority in Qatar (2019)

summer (ranging between 40 and 50 °C), high evaporation rates with an annual average of 2200 mm, and high relative humidity (Table 1).

Because of the imbalance in rainfall and evaporation, there is no surface water, limiting Qatar's local usable water supply to groundwater (Shomar et al. 2014). Further, it is difficult to directly collect surface water runoff due to the low elevation at the surface and the heavy evaporation rate. As a result, groundwater recharge is shallow (Ahmad and Al-Ghouti 2020). As a result, water security is a crucial issue for Qatar. Compared to a world average of 6500 m^3 per capita in 2017, Qatar, with 21.98 m^3 per capita, has one of the lowest freshwater availability globally (FAO 2021).

As a result, Qatar's water mix is based on seawater desalination, for domestic use, groundwater, for agricultural usage, and just a tiny amount of treated sewage effluent (TSE) used for fodder processing and landscaping (FAO 2013). In 2014, the total treated wastewater used for agriculture reached 65 million m^3 (22%) out of the total water used for agriculture, which was 295 million m^3 (Planning and Statistics Authority 2017). However, there is little motivation for using treated wastewater in Qatar. As indicated by Dare and Mohtar (2018), the public and farmers in Qatar still consider wastewater as waste, thus limiting its use despite the high quality, the substantial public expenditures, and the scarcity of water resources.

Second, as outlined by Karanisa et al. (2021, p. 9), Qatar is located on shallow and dry soil, often consisting of coarse texture, limited water retention, and sluggish soil formation, thus considered poor agricultural soil. Indeed, the majority of Qatar's soils are infertile and arid. They are salty and lack nutrients and organic matter. Depression soils, locally referred to as Rodat, are the only agricultural soils in Qatar, covering only 2.4% of the country's total land area. In 2017, just 17.8% of arable land was cultivated (Planning and Statistics Authority 2017). Meanwhile, increased local food development necessitates a significant expansion of water and energy supplies, as well as intense land usage (Daher and Mohtar 2015).

Third, certain systemic factors restrict local food production as well. In Qatar, farming practices are obsolete and ill-suited to local circumstances (GSDP 2011). The low usage of modern agricultural methods and machinery, as well as improper crop and livestock mixes, have limited the sector's productivity. In general, agricultural yields are lower than in other Gulf Countries (GSDP 2018). Furthermore, current agricultural development laws and regulations do not align with the country's food security strategies (GSDP 2018). Finally, as demonstrated by the Second National Development Strategy (2018–2022), due to a lack of "planning culture" and "teamwork," as well as a silo mindset, weak sectoral collaboration is a significant obstacle in Qatar to implementation progress. These issues delayed the execution of some projects and initiatives (GSDP 2018). Another structural issue is the deficiency of current information on soil fertility and the quality of irrigation water.

4 Food Security in Qatar: Limitations and Drawbacks of Import-Based Food Policies

Qatar's food security is dependent on foreign trade, exposing the country to price risk (as a consequence of food price fluctuations) and availability risk (as a consequence of import disruption or export restrictions) (Bailey and Willoughby 2013). Indeed, as shown by the 2007/2008 global food price crisis, food imports are more susceptible to climate and market shocks. Additionally, as is the case in the GCC region, the future of Qatar's food supply is jeopardized by a variety of factors (Ben Hassen and El Bilali 2019a).

Firstly, since climate change is projected to directly impact agriculture production through yield declines (OECD & FAO 2018), agricultural commodity prices will be volatile shortly, leading to export restrictions and speculation (Willenbockel 2012).

Second, amid the recent decrease in food prices, various systemic factors increasing prices and unpredictability remain. Population growth, income growth, and demand for biofuels will keep prices from dropping back to the early 2000s levels. Global supplies are expected to remain tight and lean as production growth lags behind consumption and stock-to-use ratios fail to recover, putting global supply in jeopardy (Bailey and Willoughby 2013). As a consequence, analysts widely assume that owing to their dependence on foreign food sources, Qatar and the GCC, in general, are highly susceptible to price and supply volatility in global food stocks, such as the one that occurred in 2007–2008 (Babar and Kamrava 2014; Ben Hassen and El Bilali 2019a). Additionally, as a small country, Qatar has little negotiating power in foreign food markets (Embassy of the Kingdom of the Netherlands in Doha 2019).

Thirdly, according to Bailey and Wellesley (2017), the biggest threat to food-importing nations like Qatar is their dependence on global commercial chokepoints (e.g., marine straits, ports, and internal transportation networks) rather than land borders. Indeed, Qatar is one of the most vulnerable countries to potential threats to food security posed by maritime chokepoints, especially for strategic commodities such as wheat. Located on the eastern side of the Persian Gulf, Qatar's sole marine gateway to the rest of the world is the Strait of Hormuz. As a result, any confrontation in the Strait of Hormuz would delay food delivery and imperil Qatar's food security, as the nation is entirely reliant on Persian Gulf ports (Bailey and Wellesley 2017; Bailey and Willoughby 2013).

In 2008, when a food crisis hit the planet (rising commodity prices, protectionist trade measures, soaring logistics costs, etc.), Qatar became fully aware of its vulnerability. Indeed, the food crisis of 2008 served as a wake-up call to all food insecure nations such as Qatar, and food security became an ongoing challenge (Babar and Kamrava 2014). Although provided with a large foreign exchange reserve, the Qatari government has understood that food prices' instability and volatility on international markets could hinder its food supplies. Following the crisis, Qatar used various policies, such as creating the Qatar National Food Security Program (QNFSP) and international investments, to manage price and supply risks.

- **The Qatar National Food Security Program (QNFSP)**

  Created in 2008, the Qatar National Food Security Program (QNFSP) is a proactive strategy to limit food imports and supply 40% of Qatar's food consumption domestically by 2030 by developing a sustainable local agricultural sector (Abrahams 2013). QNFSP focused on four key areas: water management and desalination techniques; renewable energies, especially solar energy; agricultural development through the adoption of advanced technologies; and food processing through creating an agro-industrial park (Ismail 2015). The QNFSP team released a 10-year strategy to enhance food and water security in Qatar in 2013. The strategy advocated increasing local capacity to produce and store food, relying on the private sector and foreign purchases. However, the government was compelled to drop the original proposal in favor of foreign acquisitions and long-term contracts for food imports due to the financial and environmental costs, which are projected to outweigh the costs of importing food (Al-Ali Mustafa 2017; Ismail 2015).

- **International Investments**

  After the 2007–2008 food crisis, the Qatar Investment Authority (QIA), Qatar's sovereign fund, established in 2008 Hassad Food to follow a foreign farmland investment policy. This policy seeks to enhance food security by producing overseas what cannot be produced domestically to maintain control of the food supply chain. Since 2008, Hassad has acquired or leased thousands of hectares of farms and significant stakes in agricultural enterprises in several countries, such as Australia, Sudan, Oman, Brazil, and Turkey (Efron et al. 2018; Hassad Food 2021; Woertz 2011).

  However, these investments are uncertain and raise some ethical and geopolitical issues. Many of the international investments have gone to African countries, where food shortage is still an issue. Crop exports from those countries may intensify current food insecurity and hunger, as well as trigger political upheaval (Efron et al. 2018). In addition, with most of the skilled workforce and agricultural inputs imported, the local economic benefits of these investments remain limited. Consequently, these investments were widely criticized and described as "land grabbing" or "agro-colonialism" by many NGOs and farmers' organizations (Al-Ali Mustafa 2017). For example, in 2009, a projected investment of

40,000 hectares of agricultural land in Kenya was canceled following intense criticism from the media, NGOs, and local communities (The National 2009). Hassad was wary of investing in developed and politically troubled countries after his experience in Kenya. In 2009, Hassad Food announced its intention to invest in established agro-companies rather than lease land rights and set up agricultural operations from scratch. As a result, Qatar has halted foreign agriculture ventures until land resources disputes can be resolved in a mutually beneficial manner (Arabian Business 2009).

5 Qatar's Food Security and the 2017 Blockade

On June 5, 2017, Saudi Arabia, the United Arab Emirates (UAE), Bahrain, and Egypt broke diplomatic and economic relations with Qatar and placed the country under a sea, land, and air blockade. Qatar was accused by the four countries of funding militant groups, keeping solid links with Iran, and meddling in their domestic affairs (Coates Ulrichsen 2020). As a consequence of the embargo, Qatar has been deprived of food supplies from Saudi Arabia, highlighting the country's dependency on imports (Ben Hassen and El Bilali 2019b; Koch 2021). Prior to the blockade, Saudi Arabia and the UAE accounted for 27.4% of Qatar's food supply (Embassy of the Kingdom of the Netherlands in Doha 2019). Meanwhile, 35% of Qatari food supplies, especially basic items, came from or passed through these countries, which now block borders and trade, and Saudi Arabia was Qatar's primary poultry and dairy provider (Miniaoui et al. 2018). Indeed, prior to the June 2017 blockade, Saudi Arabia was Qatar's largest dairy commodity exporter, accounting for 45.1% of dairy imports (Kaitibie et al. 2019). Following the embargo, Qatar has placed increasing local agriculture production and securing its food supply at the top of its priorities for national security reasons. Thus, the authorities carry out an extremely proactive policy and have placed significant financial resources at this ambition's service (Ben Hassen and El Bilali 2019b).

Firstly, to cope with the transportation ban, based on coordinated diplomatic actions, Qatar has rapidly managed to establish alternative trade routes and find new suppliers, with new trade partners, especially Turkey, Iran, Pakistan, and Oman (Efron et al. 2018; Miniaoui et al. 2018). The remarkable aspect of the embargo was how swiftly Qatari authorities were able to respond to the crisis and create alternative trade channels (Al Jazeera 2019b). Accordingly, following the blockade, the list of the most important food exporters to Qatar changed dramatically. In 2017, Saudi Arabia's food exports to Qatar fell by 99.3%, and UAE fell from second to ninth. Turkey emerged as the top food supplier during this period, with an export value of 190.7%. Turkey's exports to Qatar have surged by 50% since the boycott, compared to 2016 (Gulf Times 2018). Qatar's crisis has presented an opportunity for Turkey and Iran to supply food products to Qatar. Indeed, in less than 48 h after the blockade's start, the most immediate support for Qatar came from Turkey, which sent cargo planes to avoid potential food shortages (Al Jazeera 2019a). Iran as well has taken advantage of the GCC fracture. Indeed, Iran has grasped the opportunity given by a fragmented GCC and promptly aligned with Qatar. Ships of food and medication sent by Iranian authorities arrived in Qatar following the proclamation of the embargo (Pradhan 2018, p. 438).

While one country could have been the main source of more than 30% of Qatar's imports of essential commodities before the blockade, import volumes are now being managed strategically to ensure that the dependence rate on one supplier country always remains less than 30%. Relying on a single source to secure imports is no longer an acceptable option, which effectively mitigates risks related to securing supply chains and reduces dependency (Himpel 2020).

Secondly, since larger container ships cannot berth in Qatar ports due to the shallow waters, shipping lines depend on feeder services that carry containers from the port of Jebel Ali in Dubai. Qatar has chosen to rapidly restructure its maritime trade routes and shifted its supply chain from Jebel Ali Port to Salalah and Sohar's Omani ports to overcome this obstacle. On June 11, 2017, Mwani Qatar announced the launch of two new shipping services between Qatar's Hamad Port and the Omani ports of Sohar and Salalah (Reuters 2017). Additionally, Qatar has improved its ports to prepare them for additional traffic and improved port and rail infrastructure. Trade by sea from and to Qatar (excluding hydrocarbons and by-products) was severely disrupted following the blockade, but the authorities' rapid reaction, through the opening of new routes to Hamad Port, has generated a sharp rise in sea freight volumes. Launched in 2011 with an envelope of 7.4 billion USD, the Hamad Port covers nearly 30 square kilometers south of Doha. It is operated by Mwani and Qterminals, under the supervision of the Ministry of Transport and Communications. Hamad Port includes a deep-water commercial port currently equipped with a container terminal with a yearly capacity for 1.7 million tons of general freight and 1 million tons of grain, a terminal for other freight, and a mixed terminal. Partially operational since the end of 2015 and officially inaugurated in September 2017, the port accelerated its development following the blockade, generating a sharp rise in freight volumes of nearly 80% between 2018 and 2017 to reach 27.5 Mt compared to 15.4 Mt. Today, the port provides a commercial access to about 150 countries, including direct links to ports in Oman, Kuwait, Turkey, India, and Pakistan (Mwani Qatar 2021). The growth in maritime trade pushed the authorities to advance the launch of Phase II of Hamad Port, which will involve the construction of a new container terminal, a set of food storage infrastructures for staple foods (rice, oil, sugar), and a second free zone, dedicated to processing food (Mwani Qatar 2021).

Thirdly, this exposed the limitations of food import policies and the importance of increasing local production in Qatar (Ben Hassen and El Bilali 2019b). "One of the positive outcomes of the blockade is that it has galvanized Qatar to exploit its agricultural production potential" (Miniaoui et al. 2018: p. 7). As explained by Coates Ulrichsen, in the future, "…even if the siege were to be lifted, the odds are good that Qatar would avoid become dependent again on Saudi Arabia for its food security, due to the fact that Qataris saw how such a reliance on the Qatari-Saudi border for food imports could be a major vulnerability" (Al Jazeera 2019b). After the blockade, the Qatari government increased its efforts to promote local food production, including low-interest loans to farmers, guidance, and assistance to farms with agricultural production requirements such as seeds, fertilizers, pesticides, and marketing/packaging. For example, in April 2019, the Ministry of Municipality and Environment (MME), which is in charge of agriculture in Qatar, created a department dedicated to food security, focusing on increasing local food production. In addition, following the blockade, the agricultural sector had to adapt very quickly and has undergone a remarkable transformation, mainly to avoid shortages (Al Jazeera 2019b).

Prior to the blockade, domestic vegetable output met just 10% of domestic demand. Two-thirds of Qatar's 1400 farms are non-commercial and are used by families for personal use. However, the crisis has prompted Qatar to increase its local production of food commodities in which it has a comparative advantage in its production, such as fresh vegetables, milk, dates, red and white meat, eggs, and fish. Consequently, between 2017 and 2018, Qatari farm output quadrupled, helping the country to meet more than 90% of its chicken and dairy product needs. Qatar's national food security policy targets to generate 70% of its food needs by 2024 (Castelier and Clément 2018).

Additionally, Qatar has established a long-term food security strategy (2018–2023) to unify the relevant stakeholders' efforts, achieve the optimal use of the country's natural resources, and protect and enhance local production. Across four major pillars and 13 initiatives, the Strategy aims as well to make the local food system more robust against potential supply shock scenarios in the future. The first pillar is to increase local production of fresh products, such as dairy products, vegetables, poultry, seafood, and meat since they need lesser water and soil. The second pillar focuses on creating strategic reserves of non-perishable items (cereals, sugars, oilseeds) that Qatar cannot produce. The third pillar focuses on international trade to diversify procurement sources rather than depending on defined sources to prepare for any emergency that may impact imports. Finally, the fourth pillar of the plan is the domestic market, which seeks to strengthen Qatar's supply chain to ensure the delivery of high-quality products and food supplies at a reasonable price and expand market and auction mechanisms (Table 2).

For three years, Qatar has thus multiplied initiatives to find the right international trade partnerships, develop local agro-industrial sectors through financial aid for entrepreneurship and strengthen its storage system. In March 2019, Qatar's Ministry of Municipality and Environment (MME) announced several projects to boost food production to achieve self-sufficiency by 2023 for many items, such as vegetables, fish, poultry, and red meat (Fig. 2).

Also, the National Food Security Strategy includes a complementary pillar related to research and development (R&D), which aims to encourage research efforts in the agricultural sector to find scientific and technological solutions to increase production by exploiting available resources and finding alternative resources. Several policies and projects have been developed to implement this pillar, including a new research fund dedicated to food security in cooperation with the Qatar National Research Fund (QNRF). This fund was created in 2019 to promote efficient and sustainable food systems that improve food security, nutrition, and resilience (QNRF 2019).

Table 2 Qatar National Food Security Strategy (2018–2023)

Pillar	Initiatives
International trade and logistics	1. Diversify trading partners by having 3–5 partners per key commodity to mitigate Qatar's vulnerability to external influences 2. Prepare mitigation measures in advance to diminish the effects of trade fluctuations or other exogenous disturbances
Domestic self-sufficiency	3. Boost vegetable production by setting up a hydroponics greenhouse cluster to achieve 70% self-sufficiency in greenhouse vegetables (e.g., tomatoes, pepper, cucumber, squash, lettuce) 4. Increase and boost red meat production capacity (sheep and goat breeding farms) and fisheries (fish farms) 5. Limit fresh milk and poultry production to 100% self-sufficiency by canceling bids and reallocating capacity to other uses 6. Moving to TSE to reduce ground water-based fodder production
Strategic reserves	7. Leverage the private sector to store various items as a durable short-term reserve against system shocks 8. Provide strategic stocks of perishables and non-perishables as a precaution against future trade and supply disturbances 9. Rise potable water supplies as a precautionary measure against potential crises 10. Reduce net Aquifer exhaustion by maximizing agricultural water use
Domestic markets	11. Simplify the local go-to-market model to maintain pricing transparency and help farmers increase production and commodity quality 12. Implement an innovative food waste management scheme that includes agricultural waste processing, disposal, and reuse 13. Improve and simplify the governance of Qatar's food safety standards to further track food safety and supervise quality assurance systems

Source Ministry of Municipality and Environment (2020b)

Meanwhile, Qatar's investments in the food industries sector have increased by 126% to 1.4 billion $ in 2019 compared to 0.6 billion in 2016 (The Peninsula Qatar 2019).

Between 2017 and March 2020, the self-sufficiency ratio for vegetables increased from 20 to 27%; from 84 to 86% for dates; from 44 to 54% for green fodder; from 28 to 106% for milk and dairy products; from 50 to 124% for fresh chicken; from 13 to 18% for red meat; and 14% to 28% for table eggs (Al Sharq 2020). Finally, in June 2020, the Ministry of Municipality and Environment (MME), in cooperation with Mahaseel Company, launched the Daman program to support local farms through pre-contracting for the purchase of their vegetable products for the 2020/2021 season, to set guarantee prices for the purchase of local farm products, and for the farmers to set their production plan according to the needs of the local market (Ministry of Municipality and Environment 2020a).

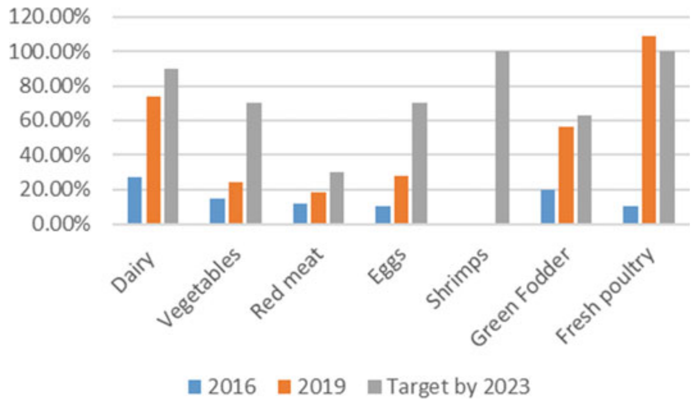

Fig. 2 Evolution of self-sufficiency for some agricultural products in Qatar. *Source* Authors' elaboration based on data from the Peninsula Qatar (2019) and Alpen Capital (2019)

6 Discussion and Conclusion: Toward a Productive and Sustainable Local Food Production in Qatar

Since the blockade of 2017, Qatar's food system has experienced a significant transformation with a vital production increase to realize the highest possible self-sufficiency level. Further, while the contexts for the 2017 blockade and the current COVID-19 situation are somewhat different, it seems that these interventions positioned the country especially well for the COVID-19 outbreak (Himpel 2020). As highlighted by KPMG (2020) "Qatar has successfully overcome similar challenges during the blockade and had already established a strong supply chain network. This preparation has allowed food retailers to manage supply chain challenges during the current pandemic effectively" (p. 17).

However, many challenges remain, and this transformation has a cost. Although local food production is less prone to climate and market shocks than food imports, it is significantly more costly when all factors are considered. Indeed, Qatar's flourishing local food industry is vastly resource-intensive and has exacerbated pressure on scarce local resources. Consequently, the chapter confirms that increasing local food production and its sustainability in Qatar needs policies that promote sustainable agriculture with high water and land use efficiency and the capacity to innovate in terms of technology, practices, and products continuously.

Firstly, one of Qatar's critical issues of water security is the constant depletion of its aquifers. Open field irrigation methods are commonly used in Qatar, resulting in low water use efficiency, high losses from evaporation, and overexploitation. Since 85% of agricultural water is groundwater, aquifers have become over-exploited, resulting in decreased groundwater volumes, seawater infiltration, deteriorated water quality, and increased aquifer and soil salinity. In 2016, the pace at which natural renewable resources are recharged (217 million m^3/year) was less than the usage rate (319 million m^3/year), implying a 102 million m^3/year annual depletion rate

(GSDP 2018). It is estimated that groundwater is pumped at roughly 220 million cubic meters per year, compared to a recharge rate of 56 million cubic meters per year. Increased water salinity has culminated in soil erosion and a decrease in crop yields, as well as farm abandonment (FAO 2013). As a result, agricultural water use is inconsistent with the value produced by the sector. Agriculture uses 40% of the overall water supply and provides just 10% of national food demand. Additionally, agriculture contributes just 0.13% to GDP and hires just 1.3% of the labor force (GSDP 2011). Consequently, local agriculture is energy-demanding due to the need to desalinate saline aquifers (Embassy of the Kingdom of the Netherlands in Doha 2019).

Secondly, following the blockade, Qatar immediately substituted Saudi milk by expanding its own dairy industry by importing 18,000 Holstein Friesian cows (BBC News 2017). While they are considered the world's best milking cows, this breed is heat sensitive and must be housed in temperature-controlled stables, while each cow needs 30–50 gallons of water a day. Also, the cooling systems used in dairy production consume a significant amount of energy and water (Wellesley 2019). According to some experts, Qatar can explore alternatives and substitute current Holstein cows with a more suitable breed to the country's environmental conditions (Washington Report 2020).

Thirdly, food waste is an important challenge in Qatar. Qatar and the GCC have an evident food-related paradox; although the six countries are heavily dependent on food imports to satisfy their rising populations' food demands, they rank among the world's highest food wasters. Indeed, they waste approximately one-third of imported food, and their per capita food waste is more significant than developed countries in Europe and North America (El Bilali and Ben Hassen 2020). Fourthly, as highlighted by Karanisa et al. (2021), Qatar's fertile depressions are also "areas that support much of the native flora and fauna. Habitat loss because of increasing agricultural production could put at risk the already imperiled native species which perform crucial ecosystem services" (p. 9).

There is little chance of solving the future of food security in Qatar unless the natural, environmental, and structural obstacles and constraints impeding agricultural production are adequately addressed (FAO 2013). Indeed, as Qatar tries to increase domestic food production, it must resolve the connected food, water, and energy constraints. As a result, a shift to sustainable food systems that guarantee food and nutrition quality is needed. To reconcile the dual goals of productivity and environmental sustainability, innovations and technologies must be tailored to the local climatic and soil conditions. Innovations of different but complementary natures organizational and social (structuring of the agricultural profession), and, of course, technical (water and land saving technologies, such as hydroponics, greenhouses, modern irrigation systems, etc.), can foster this transition. As demand for domestic and agricultural water rises, desalination technologies based on renewable energy are possible substitutes for existing fossil-fuel technologies. Additionally, the usage of treated wastewater would rise in order to prevent freshwater aquifer depletion.

Knowing that enhancing local food production requires innovation, technology adoption, and close collaboration between the different stakeholders, it will be easy to recognize the importance of studying the main obstacles and factors that influence these elements and what this implies for knowledge production and exchange consequently innovation. However, information about the different types of innovations embraced by farmers in Qatar to improve food production is rare, and little is known about technology adoption within the agriculture sector (Ben Hassen and El Bilali 2019a). Innovation is a fundamental challenge for Qatari agriculture. The lack of current research on the dynamics of innovation and technology adoption in Qatar's agriculture sector and its relationship to food security and sustainability creates a substantial and concerning awareness gap in the body of knowledge necessary to formulate successful policies.

Finally, the chapter contributes to a better understanding of the sustainability issue of food security in Qatar, which is paramount to designing effective, efficient, and sustainable plans and policies. While the chapter focuses on Qatar, its results are relevant for other Gulf Cooperation Council (GCC) countries and the Near East and North Africa (NENA) regions and beyond.

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Agri-Food Sustainability and Food Security in Egypt

Islam Mohamed Kamel and Hamid El Bilali

1 Introduction

The present global food system is burdened with many limitations including population growth; the global human population is over 7 billion inhabitants, with approximately 2 out of 7 people suffering from moderate to severe food insecurity (FAO et al. 2019). Poor dietary habits and overconsumption of meat have caused severe health problems and increased the emissions of greenhouse gases (GHG) into the atmosphere (FAO 2004). Moreover, about one-third of the food produced worldwide is wasted; food waste contributes to the depletion of natural resources (e.g. water) and carbon dioxide emissions (Blakeney 2019). The planet's natural resources (e.g. soil, water, and biodiversity) are under increasing pressure by climate change (Subramanian 2018). Thus, the need for a radical transformation to sustainable agri-food systems is unavoidable.

A sustainable food system (SFS) is a complex system with interconnected processes that require several changes from local to global levels (HLPE 2014). Sustainable food systems are at the core of the Sustainable Development Goals (SDGs) to improve food security and end hunger by 2030. In this setting, sustainable agriculture is described as a system for managing plant and animal production to ensure the provision of safe and nutritious food, fiber, and other agricultural commodities as well as aesthetic and ecological services. Furthermore, it improves environmental quality, conserves biodiversity, sustains economic viability and social acceptability, and guarantees a decent life quality for the farming communities and the whole society (FAO 2014; Jakobsson and Gustafson 2012). Different farming systems are related to sustainable agriculture such as organic agriculture, integrated pest management (cf. integrated agriculture), low input agriculture, agroecology,

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biodynamic agriculture, community-supported agriculture, eco-agriculture or extensive agriculture. According to Pretty (2008), the more sustainable an agri-food system is, the more it applies the key principles of sustainable agriculture.

An agri-food system is defined as "*a web of interactions between actors, processes, institutions, and regulatory frameworks across the different stages of food production, consumption, and waste recycling of a specific food item, from field to fork*" (FAO 2018). The agri-food systems are integrated into and shaped by political, economic, social, and environmental settings (HLPE 2017). Connections between bio-geophysical and human interventions can affect activities and drivers (Fig. 1), resulting in a variety of outcomes (Fig. 2).

Transition to sustainable agri-food systems (SAFSs) is vital to achieving food security. This is particularly important for developing nations, such as Egypt, where food insecurity and malnutrition are still pressing challenges. In such a setting, this paper analyzes the transition to SAFSs in the Egyptian context, with a specific focus on organic agriculture, and its implications for food security. It addresses the following research questions:

- What is the state of the physical and institutional infrastructure of the Egyptian agri-food socio-technical regime? And how does it affect the state of Egypt's food security?
- What are the landscape factors that are creating strain on the Egyptian agri-food sociotechnical regime? And could they be a threat to Egypt's future food security?

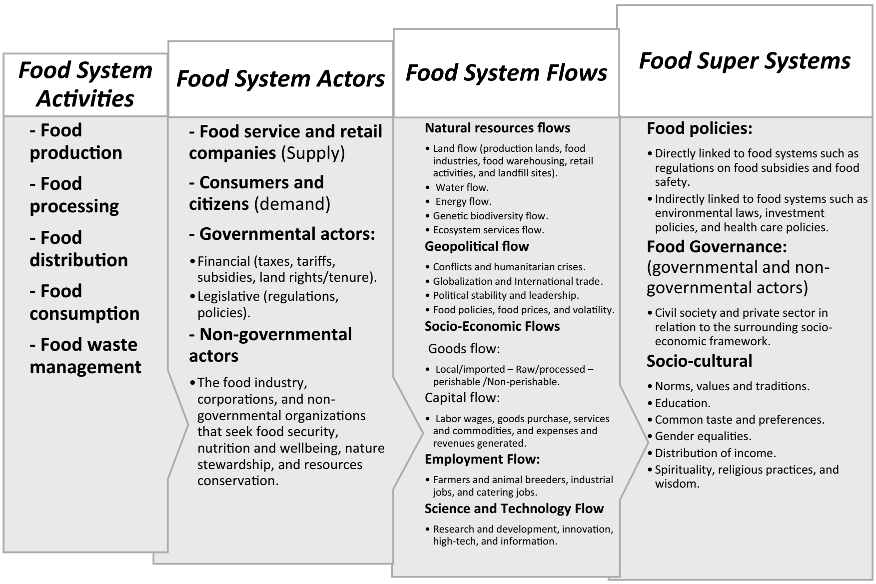

Fig. 1 Sustainable food systems activities and drivers. *Source* Authors' compilation

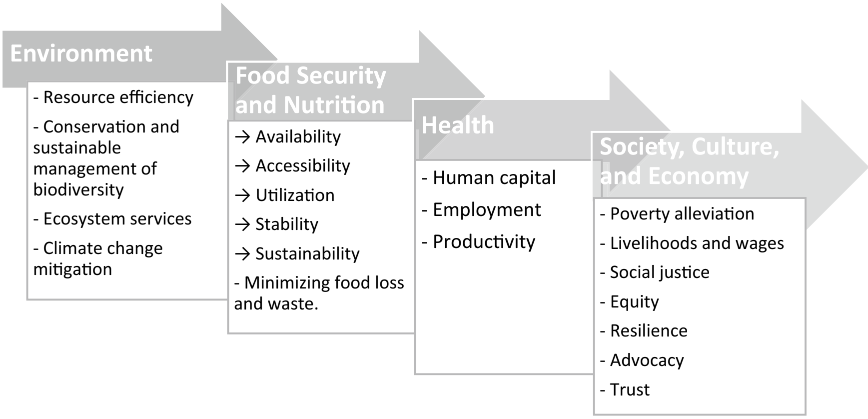

Fig. 2 Sustainable food system outcomes. *Source* Authors' compilation

- How could the process of sustainability transition to the organic agri-food system contribute to food security in Egypt?

2 Methods

Data were collected through a systematic literature review using the "Preferred Reporting Items for Systematic Reviews and Meta-Analysis" (PRISMA) (Moher et al. 2009). A search was conducted on July 15–20, 2020, using all databases of Clarivate Analytics—Web of Science. The search yielded 550 records/documents, of which 100 were chosen for their relevance to the research. Moreover, secondary data from the grey literature (e.g. institutional publications and reports) were also included.

Sustainability transition is defined as "*radical transformation towards a sustainable society, as a response to persistent problems confronting contemporary modern societies*" (Grin et al. 2010). A genuine sustainability transition in the agri-food system is needed to achieve food and nutrition security and move towards more sustainable production and consumption patterns (Fig. 3). There is a variety of frameworks used to understand and analyze sustainability transitions (El Bilali 2018). In this paper, we use the Multi-Level Perspective (MLP), a prominent framework in transition studies, especially in energy and transportation sectors. Yet, it is increasingly being applied in sustainability transition researches on the agri-food sector (El Bilali 2018, 2019).

The MLP assumes that transition arises as an outcome of the interaction between and within three analytical levels: niches, socio-technical regimes, and a socio-technical landscape (Geels et al. 2017). A niche indicates a novel technology that can alleviate or overcome challenging circumstances. The sociotechnical regime comprises the deep architecture of the existing institutional structure, including its

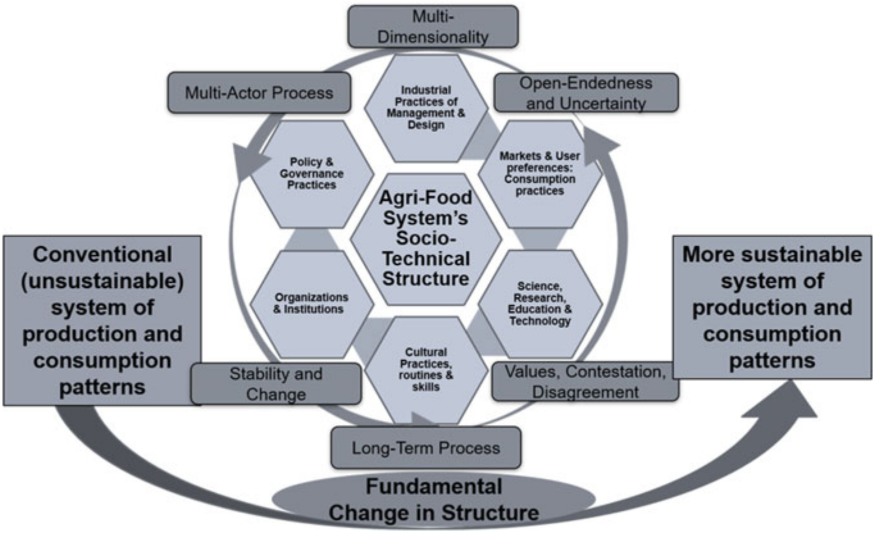

Fig. 3 Transition in the agri-food system on the socio-technical level. *Source* Authors' compilation

rules and beliefs, whether formal or informal (Geels and Schot 2007). The external factors that influence the incumbent regime are included in the socio-technical landscape, which includes both slow change patterns and exogenous shocks. The landscape factors place strain on the dominant system, enabling the development of niche innovations (Geels et al. 2017).

Accordingly, in the following section, we analyze the dynamics of transition in the Egyptian agri-food system; we shed light, first on the agri-food socio-technical regime in Egypt, then the different landscape factors that interact with the current regime and, finally, the potential implications of the development of the organic agriculture niche in terms of food security.

3 Results and Discussion

Agri-food Socio-technical Regime

The agricultural sector plays an important role in the Egyptian economy as it is the source of 55% of the people's livelihoods. The agriculture sector contributes to 17% of the nation's gross domestic product (GDP) and about 20% of the foreign currency income. Wheat, clover, rice, and cotton constitute 80% of the cultivated area in Egypt. Many of these crops feed the industrial sector with raw materials such as cotton for the textile industry (Khalaf 2017). Furthermore, Egypt's primary farming system is a mixed crop-livestock one. Around 40% of the Egyptian people rely on agriculture as their primary business. Additionally, the agri-food industry employs over 750,000 individuals; this corresponds to around 35% of jobs in the manufacturing sector and approximately 16% of the overall labor force in the country's direct employment. Meanwhile, indirect employment in the agri-food sector was estimated at approximately 2.25 million workers. The majority of producers in Egypt are small landholders (owning less than 1 ha) who represent 80% of total producers (El Mekki et al. 2015).

The overall food self-sufficiency in Egypt stands at 88% and 66.04% for cereals, with an arable land area of 3.745 million ha and an overall water resource capacity of 58.3 billion m^3 per year (Bagnied and Speece 2019). The Nile basin (Delta) is the main arable area in Egypt. The cropland has grown by 33.7% over the past three decades, with an average annual growth of 31,000 ha. Egypt was able to bring high-value agricultural goods into the local and export market as a result of the socio-ecological expansion of agriculture and food production intensification in 'reclaimed land' (Dixon 2015). Furthermore, Egypt's food sector is one of the top five with the highest labor absorption potential, due to its close interconnections with other industries and its significant effects on the Egyptian economy (El Mekki et al. 2015).

Egypt is confronted with the issue of limited arable land area, which is mainly spread around the Nile Valley and Nile Delta. Wheat, maize, and rice cover the majority of land area among the grain crops (Deng et al. 2014). Wheat is an integral part of the Egyptian diet, accounting for 60% of daily caloric and protein intake (Tadesse et al. 2017). Egypt has a high dependence on wheat imports; in 2004 and 2008, it was the third wheat importer, and in 2014, it was the second one worldwide (Dong et al. 2018), which makes it more vulnerable to global supply shocks than other countries and threatens its food security. Moreover, the subsidization of wheat in the country explains its high market demand (Veninga and Ihle 2018).

Intensive farming systems have been widely used in Egypt to address food security issues, but they have also created new environmental, social, and economic challenges (El-Essawy et al. 2019). Egyptian farmers use high quantities of synthetic chemicals; the quantity of synthetic pesticides used annually in Egyptian agriculture was estimated at the end of 1990s at around 5,756,000 tons, while mineral fertilizers were at 1,547,680 tons (Zarka 1999). However, these figures are expected to be higher after over 20 years of agricultural land expansion and production intensification. The expansion of the corporate agri-food system in Egypt reinforced two national dietary patterns: an increase in protein consumption and caloric restriction among the affluent economic class, and a change in diet toward foods heavy in fats and sugars among the impoverished class. The annual production of agricultural waste is roughly 30–35 million tons (Adel et al. 2016) and the amount of food waste is estimated to reach 250 kg per person annually in Egypt, which makes the country one of the top contributors to the global food waste (FAO 2020). Smallholders, who cover the majority of domestic market production, are being excluded from some chains due to market competitiveness and their inability to fulfill quality/safety requirements, which forces them to work under the manipulative umbrella of traders without a legal contract (Hatab et al. 2019). Many policies and guidelines are out of date, resulting in inefficiencies in production. These policies caused land fragmentation and reliance on the state's support. Furthermore, laws governing food safety, environmental protection, consumer rights, and marketing are either non-existent or insufficient. These regulations are posing a negative impact on productivity and need to be reassessed and updated (Bagnied and Speece 2019).

Socio-technical Landscape Factors in the Egyptian Agri-food System

The main landscape factors that affect the sustainability of the Egyptian agri-food system relate to the increasing population and poverty rates, water resources depletion, climate change, land degradation, and health problems.

Climate Change and Food Security

Egypt is faced with serious environmental challenges, that threaten the country's food security, such as climate change (Farag et al. 2018). Agriculture generates a significant share of GHG emissions, but it is also a sink for soil carbon sequestration. The carbon footprint of agriculture is one of the main indicators of the performance and sustainability of agricultural processes (Farag et al. 2018). According to Mansour (2016), air pollution from energy and agriculture residues contributed in 1999/2000 to 45% of the total environmental damage in Egypt. Mansour (2016) points out that all of these problems are resulting from the lack of innovation and the mismanagement of waste. Furthermore, synthetic fertilizer use contributes greatly to GHG emissions in Egypt, accounting for 45.5 and 47.2% of total GHG emissions from corn and wheat, which are the main national grain crops (Farag et al. 2018).

Land-use changes and human activities in the Nile basin across the last two decades have had a direct effect on climate change. According to Hereher (2017), converting arable land to public housing raised the land surface temperature (LST) by 1.7 °C and reduced the LST in newly reclaimed lands by 0.52 °C. Furthermore, Mohamed et al. (2019) illustrated that increasing LST, due to population growth and urban sprawl, has decreased the soil organic carbon in the Delta area. The changing climate poses a serious threat to arid, semi-arid, and low-elevation coastlines; Egypt's northern Nile Delta is one of the most susceptible areas to global sea-level rising (Refaat and Eldeberky 2016). In this regard, increasing temperature by 1–4 °C will rise sea-level by 2 m and decrease the range of agricultural land on the Nile Delta by ~ 60% (Kheir et al. 2019). Climate change is causing the deterioration of the Egyptian agriculture sector and will increase over time the pressure on the economic state (Kahsay et al. 2017). The prices of food will increase (McCarl et al., 2015) with negative effects on consumers (Nasr Ahmed et al. 2020). Pre-existing issues such as unemployment, malnutrition, human health deterioration, and economic losses may increase by the rise of temperature (Smith et al. 2014).

Water Depletion and Land Degradation

The Middle East and Mediterranean regions have the highest rates of water deficit in the world. Consequently, they have the lowest food self-sufficiency (Frascari et al. 2018). Egypt has hit the threshold of water scarcity due to intensive cropping and inadequate water usage. Therefore, the country will require a higher share of Nile water to cover the water shortage, which poses a huge threat to Egypt's agricultural output and food security (Olanya 2017). Furthermore, the construction of dams for the generation of hydraulic power at the Nile water upstream countries is causing geopolitical water issues for the downstream countries. This is foreseen in the hydraulic infrastructure development by Ethiopia and Sudan, which is jeopardizing Egypt's water share of the Nile water (Power 2014).

Water pollution is adding fuel to the fire of the water shortage and discouraging agricultural production since it decreases the quantity of suitable water. According to the statistics of the Ministry of State for Environmental Affairs (Abdel Wahaab et al. 2020), about 18.9 billion cubic meters of untreated city sewage and agricultural drainage, besides industrial waste material, are illegally dumped annually in the Nile and irrigation waterways. Moreover, a study by Agrama (2019) illustrated the high risk of groundwater pollution in the East and West of the Nile Delta.

Surface runoff and soil salinization, especially on the northwest coast, are considered very dangerous for agriculture development in Egypt (Mohamed et al. 2020). Moreover, smaller farms in Egypt are under pressure due to land fragmentation into small units, which do not produce enough income and do not economically fit the modern marketing and distribution networks (Abdelaal and Thilmany 2019). Soil sealing, resulting from the expansion of urban areas, is prevalent in Egypt because of the rapid population growth. Unfortunately, it comes at the expense of the limited arable land, which led to dramatic consequences on agricultural productivity and the environment (Radwan et al. 2019). Urban sprawl increased in the Nile Delta area by fivefold from 1972 to 2017. As a result, increased urbanization has contributed to the depletion of soil carbon as well as a switch in farming from the fertile old land beside the Nile to the poor marginal desert land that necessitates excessive external inputs (Radwan et al. 2019).

Health Problems

Diabetes, chronic respiratory health problems, cardiovascular diseases (CVD), and cancers are the leading causes of death worldwide, accounting for 72% of the overall deaths in 2016. These diseases are caused by poor eating habits and unhealthy lifestyles. Egypt and Pakistan had the greatest total fat consumption in the Eastern Mediterranean countries; in Egypt, CVD accounted for 40.4% of the total fatality cases in 2016 (Jawaldeh and Al-Jawaldeh 2018). The mortality rates of breast cancer in Egypt are among the highest in the Middle East (Gany et al. 2020). Furthermore, Mahfouz et al. (2014) indicated that the major risk factors for colorectal cancer in Egypt are linked directly to the excessive intake of lean and processed meat, artificial food preservatives, sugar substitutes, fast food, and sodas as well as smoking, and the reduced physical activity.

Obesity in Egypt accounts for 75% of women and 60.7% of men (MoHP and ICF 2015). Micronutrient deficiency affects about 81% of the total obese mothers. Overweight and anemia amongst non-pregnant women reached 77 and 28%, which shows that obese women's iron requirements are not being met, and their micronutrient consumption may be inadequate (Eckhardt et al. 2008). Egypt ranks 20th worldwide in terms of the number of children with chronic poor nutrition; around 21.1% of children under the age of 5 had malnutrition-related stunting, while 9% were suffering from wasting, and 15% were classified as overweight. Moreover, one out of every eight newborns is delivered with low birth weight. Children from poor households are most likely to have nutritional health problems (Chemeda and Abdel-azim 2018; Abdelaal and Thilmany 2019). Egypt's subsidization of high-calorie foods, which form a large part of the diet of the poor especially in rural areas, might also be another reason for obesity since food choice is driven mainly by food affordability (Kavle et al. 2018). Consumption and production subsidies have negatively affected the economy. As a consequence, 30 years of focusing only on agribusiness has not resulted in significant food security or effective use of natural assets (Tanyeri-Abur and Hag-Elamin 2011).

Population Growth and Poverty

The Egyptian population has increased from 45 million in 1981 to 85 million in 2011; as a result, Egypt has become one of the fast-growing and largest societies globally. The unbalanced population density, since all the population is concentrated in about 6% of the country's total land area around the Nile River (mainly Nile Valley and Nile Delta), and the rapid population growth (about 2% annually), has triggered severe socioeconomic issues (Veninga and Ihle 2018). Inadequate access to already scarce resources and limited possibilities for increasing the cultivable land area is putting more economic pressure on Egypt and jeopardizing its ability to achieve long-term food security (Radwan et al. 2019). From 1999 to 2015, poverty has risen dramatically from 16.7 to 27.8% (Mansour 2016; Abdelaal and Thilmany 2019). A high rate of unemployment is prevalent among young people; 29% among males and 45% among females in 2016 (Nasr-Allah et al. 2019). About 75% of the labor force is in informal sector jobs that are not adequate for sustaining decent living standards. Egyptian youth are still off track; claims for equality, social justice, and a brighter economic status are the main challenges facing the Egyptian society (Mansour 2016).

These factors are considered to be a result of capitalism, which is regarded as a system of unlimited capital growth that cannot continue with limited resources in a finite physical environment (Feola and Jaworska 2019). Ever since the Ottoman conquest of Egypt in 1517 until the mid-eighteenth century, the expanding presence of the Egyptian elite capitalists and the advent of industrial agriculture have forever transformed the rural society, farmers' activities, and the interactions with natural assets (Mikhail 2014). Nowadays, Egypt's agri-food corporates are dominated by a few rapidly expanding businesses that generate about 40% of the overall value of agricultural exports (Dixon 2014). The stability of Arab countries was affected by the so-called 'Arab Spring', which was the outcome of corruption and deceit, capitalism as well as privatization that put the nation in the grip of privileged elites who shaped its policies to benefit themselves rather than the community (El-Haddad 2020). Government shortcomings and neglect of state obligations are shown by the high food costs, low quality of living conditions and health care, environmental degradation, and education quality decline (Mansour 2016).

Transition to organic agriculture and food security

The organic farming production system is at the center of a heated debate, particularly when it comes to global issues such as food security and climatic problems. There are several arguments about how food must be produced, however, no one can deny the necessity of transition towards a more sustainable agri-food system (Connor 2018). Organic agriculture (OA) is an integrated farming system that relies on the use of on-farm renewable resources to meet the needs of crops, livestock, and humans. Although it grows food without the use of any synthetic fertilizers, pesticides, or genetically modified organisms (GMO), it protects the crops from pests and diseases through a holistic management of resources as well as knowledge of ecological cycles and biological processes (Crespo-Herrera and Ortiz 2015). Meanwhile, food security is a multifaceted issue, involving food availability, accessibility, utilization, and stability (FAO 1996). OA within the Egyptian context is proposed as a niche whose development can affect each food security dimension, as discussed below.

Food Availability

The term 'availability' refers to the supply of adequate quantities of appropriate-quality food, through domestic agricultural production, food imports, or food aid (Zundel and Kilcher 2007). Many scholars argue that OA can produce adequate food to feed the whole world as the core problem is not 'food availability'. The production on a global scale is more than enough to feed the world's population; the problem is food accessibility (FAO 2007). However, the lack of education and proper agricultural training for small organic farmers in developing countries is resulting in a yield gap of 30–40% compared to the conventional farming system; this yield gap would increase the need for about 43 to 67% of land to substitute the same food quantity (Qaim 2017). Nevertheless, with intensive training on the utilization of organic amendments and fertilizers, organic production can be higher than in low-input conventional farming (Ibanez and Blackman 2016).

Land tenure problems, labor availability, a wide range of technologies (e.g. leguminous seeds, composting facilities, low-impact biocides), and site-specific infrastructure-related issues remain hard to handle (Meemken and Qaim 2018). Besides, the insufficient food system assets as in the case of Egypt—represented mainly in the limited arable land (cf. less than 0.03 ha per capita) and scarce water resources—and population growth are a great concerns for long-term food security (Kamel and El Bilali 2020). Still, many scholars pointed out that OA can have a substantial contribution to the desert reclamation in Egypt when it comes to the promotion of soil fertility and efficient water use (Köberl et al. 2011; Mansour et al. 2019; Gao et al. 2020). Yet, it is critical to establish adequate methods to minimize the consequences of runoff by improving the efficiency of water collection systems and water drainage (Mohamed et al. 2020).

Food Accessibility

Food accessibility describes the persons' entitlements to acquire nutritious foods (Scialabba 2007). Many impoverished households in developing and emerging nations spend more than half of their budget on food. In such cases, rising food costs is connected with greater levels of food insecurity and malnutrition, particularly in metropolitan areas (Meemken and Qaim 2018). People's ability to buy affordable and healthy food in Egypt has been impaired by high levels of deprivation, unemployment, and economic reform measures that have resulted in a rise in living costs while maintaining the same low wages (Kick et al. 2017). Organic farmers may increase food production in market-marginalized areas by utilizing local resources rather than relying heavily on external supplies or food delivery networks over which they have limited control (FAO 2007).

The majority of organic farmers in developing countries grow cash crops for exportation to wealthy nations, where consumers pay a substantial premium for certified organic goods (Willer and Lernoud 2018). However, different players in the supply chain often capture some of the benefits; the retail price premium does not always represents the price that farmers obtain for their organic produce (Minten et al. 2018). Organic farms smaller than 8 ha in Egypt use a contract farming structure (Oelofse et al. 2010), while big organic farms sell directly on the domestic or foreign markets. Furthermore, in certain cases, organic farmers in developing countries earn prices that are comparable to those on conventional markets (Parvathi and Waibel 2016). Egypt's transition to OA is hampered by a lack of political support structure, legal framework, expertise, and technology transfer (Kamel and El Bilali 2020). The government support policies and subsidies to small organic farms can affect conventional farmers' decisions to convert to organic practices (Brenes-Muñoz et al. 2016).

Food Utilization

Food utilization refers to a condition of good nutritional health and wellbeing in which all physiological needs are met. This state is achieved through the consumption of a safe and balanced diet, and drinking clean water (Scialabba 2007). Organic farming can advance food security by reducing water pollution and preventing the use of chemical fertilizers and pesticides, which contaminate groundwater and water reservoirs by leaching and runoff (Sivaranjani and Rakshit 2019). Organic farming, resulting in increased livestock immunity and decreased antibiotic resistance, also plays a significant role in preventing pesticide poisoning at the workplace (Scialabba 2007). Furthermore, organic food intake is being discussed as a way to improve human health and reduce the incidence of chronic diseases, which are a major concern in Egypt (Hurtado-Barroso et al. 2019). However, Egypt's food security problems will be solved not only by switching to a more sustainable production system but also by introducing educational and health awareness campaigns at both the supplier and customer levels (Abdelkader et al. 2018). Small farmers make up the majority of the Egyptian society (El Mekki et al. 2015); thus, converting more small farms to OA will benefit not only the farmers' income and the availability of organic goods on the markets, but also the wellbeing of farmers and their families. By doing so, OA can provide nutritious, clean, and affordable food to one of the most disadvantaged societal segments that is directly exposed to pesticides and chemicals, practice an unhealthy lifestyle and has poor eating habits. As a result, OA will help to address one of Egypt's most pressing challenges, namely health issues.

Food Stability

Food stability refers to the constant ability to obtain sufficient food. Concerns about economic and climatic crises or seasonal food insecurity, arising from climate change and erosion of environmental services, are a potential threat to ecosystem resilience and food security (Scialabba 2007). Climate change may develop indirect causes of social volatility and unrest in North Africa. To alleviate the impact of climate change, it is essential to decrease economic and livelihood reliance on rain-fed agriculture and reinforce sustainable land-use practices (Schilling et al. 2020). Many studies have discussed the paybacks of OA when it comes to improving soil quality and fertility, by using manure and compost, crop rotation, intercropping and adopting effective nutrient recycling. These practices are thought to enhance soil quality, mitigate climate change, and strengthen the agri-food system resilience (Hole et al. 2005; Kukreja and Meredith 2011). Egypt can mitigate environmental challenges through improving extension and agricultural technologies, using indigenous resistant varieties, and, most importantly, increasing the use of water conservation strategies (McCarl et al. 2015).

4 Conclusion

The poor condition of the physical and institutional structure of the Egyptian agri-food socio-technical regime has affected the country's food self-sufficiency and aggravated the socio-technical landscape factors (e.g. climate change) that pose a significant risk to food security. Future food supply and availability are vulnerable to a limited arable land area and water shortages that are exacerbated by climate change. Furthermore, poverty and lack of awareness limit access to quality food. Water contamination caused by the intensive use of synthetic fertilizers and pesticides has become a serious issue. Consequently, the expansion of the organic agriculture niche is critical to foster sustainability transition in Egypt's agri-food system. This expansion is a prerequisite to attain long-term food and nutrition security in Egypt, mitigate the effects of climate change and realize the SDGs. Finally, this continuing, long-term transformation necessitates structural improvements in the regime's strategies and structure, which can be accomplished by the consolidation of stakeholders' engagement at all levels. Networking between specialists and consultants, advancing agricultural science, enhancing extension and advisory services, and fostering agricultural technological innovation especially for small- and medium-sized farms/firms are all essential. Meanwhile, informing and raising the awareness of the public about environmental footprints of dietary habits is critical for addressing health issues and achieving sustainable food and nutrition security in Egypt.

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Community Supported Agriculture (CSA) with View at Promoting Food Security and Sustainable Agriculture

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1 Introduction

The CSA (Community Supported Agriculture) system presents an alternative model of relationship between food producers and consumers. It operates differently from the traditional market logic, valuing partnership, cooperativism and co-responsibility. CSA is associated with the Alternative Food Networks (AFN) movement, which has developed rapidly in the United States and Europe over the past 30 years, providing new forms of agricultural production and creating new networks of food systems. In

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this system, consumers are seen as co-producers, being co-responsible for production and accompanying producers throughout the production cycle. The CSA is also directly related to the 2030 United Nations Agenda on Sustainable Development Goals (SDGs). In order to provide guidelines to the countries towards a more sustainable planet for future generations, the United Nations, with its 193 member countries, presented the 2030 agenda, proposing a set of 17 SDGs. These objectives concern the reduction of poverty and inequalities, access to education and health for all, as well as responsible consumption and production and the elimination of hunger in the world. Many of these objectives are connected with family production and food production. The CSA system is directly related to the following SDGs: SDG 1—No Poverty, SDG 2—Zero Hunger, SDG 3—Good Health and Well-Being, SDG 8—Decent Work and Economic Growth, SDG 10—Reduced Inequalities, SDG 11—Sustainable Cities and Communities, SDG 12—Responsible Consumption and Production, SDG 15—Life on Land, SDG 17—Partnership for the Goals.

When it comes to eradicating hunger, it is important to emphasize that we are still experiencing food insecurity in different parts of the world. Food security is one of the main concerns of the United Nations and the Food and Agriculture Organization (FAO). Food issues are related to the availability and access to food, especially in poor countries. However, in addition to access and availability, it is also important to discuss food quality and its source. CSA aims at a more natural production, without the use of pesticides and chemicals, providing the production of healthier foods that can contribute to people's health. This system is aligned with sustainable agriculture, which aims at producing better quality food and also providing a better life for producers and communities.

The world has been experiencing a growing demand for food, putting pressure on producers and consequently on the entire agricultural production chain (Helin and Weikard 2019; Iriarte et al. 2020). With environmental pressures, demanding new forms of production that bear less impact on the environment, agricultural production must undergo adaptations, developing new production models that are more sustainable and aligned with sustainable development (Schneider et al. 2011; Ribeiro et al. 2020). With a population of almost eight billion people, a number of efforts are required today to meet the world's food demands. Countries such as China, India and Nigeria have experienced extremely high population growth rates in recent decades, creating pressure on the food production system (Gandhi and Zhou 2014). On the other hand, producing countries, like the USA and Brazil, must constantly develop their production systems, producing more and more efficiently, to satisfy the global market demand (Liebe et al. 2020; Battisti et al. 2020).

Extensive agricultural production, which aims to large scale food production, causes several environmental problems, such as deforestation, soil degradation, water pollution, use of large quantities of chemicals harmful to consumers and to the farmers themselves (Dile et al. 2013; Sobrosa Neto et al. 2018). In this sense, sustainable agriculture appears as a new form of production, which aims to reduce the environmental impact, improving food for consumers and the lives of farmers. Sustainable agriculture seeks more conscious and responsible forms of production, both from an environmental and social point of view, aiming not only at providing improvements for consumers, but also for small producers and for family farming (Garnett et al. 2013; UN 2019).

The supply of organic products on the market has caused changes in the way people consume food Consumers today are more concerned with the origin of food, seeking closer contact with producers (Ghosh et al. 2019; Jensen et al. 2018; Sepúlveda et al. 2016). In order to support sustainable agriculture and organic production, certifications or food stamps strategies emerged, a reality already present in several countries (Giuliani et al. 2017; Home et al. 2017; Saadun et al. 2018). Brazil has several social and environmental seals and certifications already used in the market, which indicates an increase in consumer awareness and a greater concern with the origin of the products (Organics Net 2020; IBD 2018; Maguire-Rajpaul et al. 2020; UTZ 2020; Brasil 2019) .

In this context, this chapter aims to present the concept and philosophy of CSA, highlighting its contributions to sustainable agriculture and food security. How can the CSA concept help us to develop more sustainable, equitable and fair agriculture in the world? How can CSA contribute to food security? To answer these questions, the work was structured as follows: initially, the concept of CSA, its philosophy and its functioning was presented to farmers and co-farmers; then we discuss the CSA's relationship with sustainable agriculture, highlighting the methods of agriculture used in the CSAs; then discussions are held on governance in the CSAs, the benefits and empowerment of farmers through the CSA system, which are the main partners that can be part of the CSA; finally, a basic CSA model is presented, presenting the functioning dynamics and roles of farmers, co-farmers and partners.

2 Sustainable Agriculture

The evolution process of sustainable agriculture, according to Kroma (2006), has been to seek ecological, social and economic benefits optimization, based on the management of a system that boosts these benefits. Among the indicators of benefits optimization, we can mention the percentage of fixed capital invested in agriculture in relation to the country's total fixed capital; the total rate of investments in agriculture in the country; the rate of agriculture energy consumption in the country; the percentage of arable/agricultural land in the total country territory and the participation of agriculture in the Gross Domestic Product—GDP (Radulescu and Ioan 2015).

In connection with the commodities market, it is noted that, in order to improve agricultural sustainability, compliance with environmental and social demands is required in many countries (Chiffoleau et al. 2016). In this sense, agroecological innovations, together with management skills, have been developed and tested in the absence of a systematic knowledge of organic practices, attributing a character of "trial and error" to the organic agriculture adopted by rural producers. Thus, to validate such innovations, these farmers have relied on interaction and sharing networks, as well as the exchange of experiences and learning (Kroma 2006). In addition, it is also up to technology driven by managerial changes to ensure that a greater economic access to food is made available, given the high number of people living in extreme poverty (Radulescu and Ioan 2015).

There are a number of factors that drive the domain of sustainable agriculture and that influence farmers' perception. These factors range from market incentives for the production of differentiated products, but especially certified food products, service level of advisory entities, presence of active environmental and social NGOs, public organizations, in addition to the perspectives and resources available to farmers (Snider et al. 2016). Migliorini and Wezel (2017) enhance that attention to social issues is extremely important for the sustainability of agricultural production.

However, there is a certain distance in relation to the achievement of more consistent objectives, with regard to the transformations observed in food systems, towards sustainability. Although this fact is evident in the food chains, the existence of an alignment between ecologically correct agricultural models and national policies is perceivable. In addition, Klerkx et al. (2012) emphasize that the growth and dissemination of sustainability in agriculture depends on social innovation, and on what sustainability proposes.

When it comes to the search for a greater general consensus in relation to the definition of sustainability goals, one can mention performance indicators such as the biodiversity preservation increase, and the reduction of the environmental impact of agricultural practices (Radulescu and Ioan 2015). In this sense, it is also up to sustainable agriculture, as a reflection of environmental principles in the context of agricultural practices, to also meet the need for fibers and for food security, in addition to ensuring the optimization of non-renewable and agricultural resources through an efficient integrated use (Agdurakhman et al. 2018).

On the other hand, considering the agricultural regime and conventional agriculture, networks of individuals and/or organizations burgeon as representatives of sustainable agriculture innovative practices and rural development, which make up the alternative and innovative approaches to agriculture (Ingram et al. 2015). Among the challenges faced by sustainable agriculture, both modern agriculture and the environment resistance stand out, in relation to the establishment of a process of reconciliation of economic and environmental interests respectively, that meet an accommodation and conservative policy (Marsden 2012).

Radulescu and Ioan (2015) draw attention to the fact that sustainable agriculture must meet the requirements that comply with the maintenance and improvement of quality of life of those involved, that is, farmers and society in addition to the requirements of agricultural operations, in the case of economic feasibility. As a proof of this challenge, there is a marked ambiguity, in the selection of agricultural sustainability indicators, considering their environmental and collective impact, for future generations, in addition to probable effects in developed and emerging countries. This scenario is represented by the current debate on the sustainability of biofuel production (Agdurakhman et al. 2018).

Among other objectives to be achieved by sustainable agriculture, we should mention, the establishment of a production system that generates less environmental impacts, the satisfaction of social needs and expectations, as well as signifying an agricultural sector with income and job opportunities (Marsden 2012; Darnhofer et al. 2010). For Muharram and Alsharjabi (2019), an agricultural production process that respects nature and the environment, as well as contributing to social growth, in a rapidly changing environment, as a reflection of the capacity and skills of the rural production center, fits into the development model of sustainable agriculture.

The importance of innovation for the development of sustainable agriculture is known, although the great leaps in productivity have been accompanied by a proportional growth of environmental damage. As a consequence, it is clear that innovation is based on parameters represented by the limits of people, planet and profit structure, in an attempt to direct innovation, since while it is necessary to reduce environmental impacts, it is up to technology to ensure productivity growth (Radulescu and Ioan 2015).

3 Community Supported Agriculture—CSA

In the current situation, the Community that Supports Agriculture (CSA) has meant a promising path for those who value eating healthy foods. According to Chen et al. (2019), CSAs correspond to an agroecological practice based on the formation of local groups that are committed to managing the entire production chain until the delivery of food to the final consumers. It is worth remembering that the groups are formed by the final consumers themselves, that is, in the CSAs model there is an approximation of the interested parties based on a joint involvement of farmers and other members of the community (Paul 2019; Matzembacher and Meira 2020).

In general, CSAs work based on the cultivation of plants for food through agroecological and biodynamic production techniques, which are distributed in pre-defined locations by the members themselves (Chang 2020). Thus, all members make the periodic payment of their baskets; however, a differential of the model is the purchase of food blindly, that is, members do not have access to which foods will make up the basket (Dong et al. 2019; Matzembacher and Meira 2020). In this way, this production model contributes to the valorization of family farming, producing fresh and healthy food and, above all, respecting the limiting factors inherent to the environment (Chen et al. 2019). It is worth mentioning that the incorporation of consumers to the dynamics of the food production system and the devaluation of the current marketing and market principles are relevant aspects of the model (Brown and Miller 2008; Chang 2020).

In addition, the implementation of CSAs contributes to the improvement of the population's eating habits and encourages organic production, free of agrochemicals (Neto et al. 2016; Chen et al. 2019). Another positive aspect is based on the reliability and security conferred to the producer, since the model is financed through fixed monthly quotas from each member of the community (Dong et al. 2019). In this way, the production system becomes more consistent, and each producer will be able to dedicate himself exclusively to the field for the generation of new foods of higher quality (Lang 2010; Chen et al. 2019).

The economic issue, although not the focus of the model, presents a challenge for some producers, in particular the measurement of the total costs of the production process (Hvitsand 2016; Krul and Ho 2017; Paul 2019). Some of these costs present difficulties, as this method requires a cultural transition, separated by the absence and existence of detailed expenditure management (Balázs et al. 2016; Torres 2017). Thus, a structuring of costs must be carried out in order to obtain control of the entire process (Matzembacher and Meira 2020). In addition, the outsourcing of this stage to members of the community is beneficial for producers, who were previously multipurpose individuals (Hvitsand 2016).

In this sense, the CSA models follow a pattern of participatory and collaborative organic structure (Brown and Miller 2008; Chang 2020). All members can express their opinion, in order to assist in the decision-making process (Cone and Myhre 2000; Torres, 2017). However, due to bureaucratic issues and level of education, some decisions end up being centralized in some members, creating a new form of structure, now with the presence of some leaders, that is, a mixed structure (Balázs et al. 2016; Krul and Ho 2017).

The CSA system has a shorter production chain than the traditional system, providing benefits such as reduced logistics and transportation costs and reduced time between harvest and delivery to the customer. This shorter chain provides many benefits for both producers and customers. Figure 1 shows the difference in the production chain between the CSA system and the traditional market system.

Another important factor is the farmers' training in the CSA system. With the expansion of the concept and healthy eating habits, the demands have grown, requiring an expansion of the production areas as well as the use of innovative cultivation techniques (Hvitsand 2016). In view of this, even with a growth in the number of adherents, the appreciation and respect for food production on a seasonal

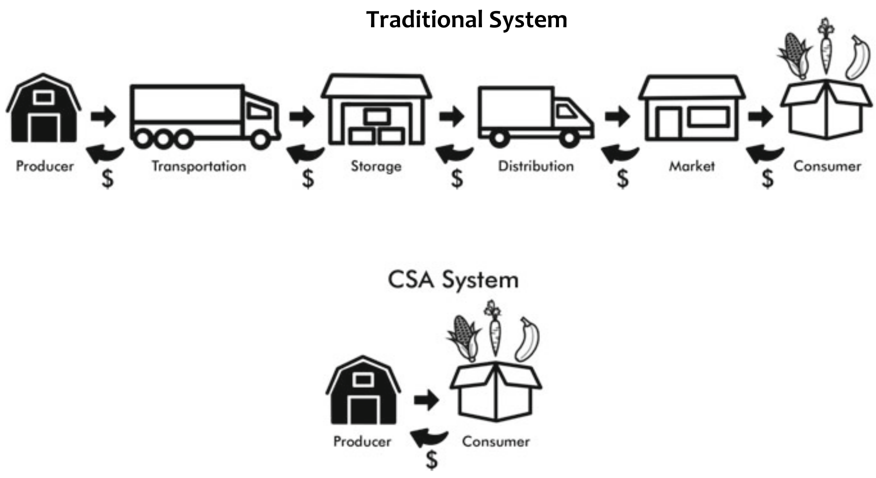

Fig. 1 The shortening of the production chain through the CSA system. *Source* Author

basis is a reality for CSAs (Paul 2019). This fact contributes to the generation of higher quality products and respects the production limits established by the environment itself (Hvitsand 2016; Dong et al. 2019). Therefore, consumers will have contact with unconventional food plants according to each period of the year (Chen et al. 2019; Paul 2019).

In conventional production models, farmers are hostages of the application of machinery, technologies, chemicals and pesticides responsible for a large part of the capital invested in production (Brown and Miller 2008; Neto et al. 2016; Amorim 2018). This fact makes CSA a new opportunity for the growth and recognition of family farming in the world (Paul 2019; Chang 2020). In addition, there is a simplification of cultivars management based on the use of conventional techniques, which reduces costs and makes the model economically self-sustainable (Torres 2017; Dong et al. 2019).

Finally, CSA also comprises a new model of self-management in which the members themselves are responsible for its maintenance, functioning and growth (Torres 2017; Paul 2019). Although the focus of the model superimposes the issue of food security over the economic issue, the implementation of CSAs contributes significantly to the lives of small farmers, generating income for them and for the acquisition of production inputs (Dong et al. 2019; Matzembacher and Meira 2020). On the other hand, the model follows the principles established by the concept of food security, ensuring the population's access to healthy and quality food (Cone 2000; Torres 2017; Paul 2019; Chang 2020).

4 CSA and Sustainable Agriculture

CSAs play an important role for farmers and the community. The CSA system recognizes the importance of small farmers, who produce respecting the environment and rescuing the cultures of the countryside, producing differentiated and quality foods (Hvitsand 2016; CSA Brasil 2021). Producers who are part of CSAs use production models aligned with sustainable agriculture, such as permaculture, agroecology, and organic or biologic agriculture.

Permaculture refers to permanent agriculture, created by Bill Mollison in 1978, which emphasizes the relationship between man and the land, establishing a balanced integration between man and the environment. This type of agriculture seeks to understand ecology, using its own natural resources in production, in a rational manner, allowing for sustainable production (Holmgren 2002; Veteto and Lockyear 2008). Caring for the land, caring for the future and caring for people are the principles of permaculture. Example of permaculture practices, applied by farmers, are the dry toilets, which aim to reduce the use of water and the treatment of organic waste; the mandala garden, for the production of food in a sustainable manner; and the earthworm raising for the production of humus used as fertilizer (Holmgren 2002).

CSAs are also aligned with agroecology, which is a form of sustainable agriculture, resuming the production conceptions that existed prior to the green revolution.

Agroecology is a philosophy of agricultural production that incorporates social, political, cultural, energy, environmental and ethical issues (Altieri 2002). The reduction of damage to biodiversity and to society, caused by monoculture, is the objective of agroecology, which does not use industrial fertilizers and pesticides. The practice of organic agriculture and the use of clean technologies seek to generate less negative environmental externalities in production. The proposal of agroecology is a revision of conventional methods of large-scale land management (Nicholls and Altieri 2018).

Organic or biologic farming, on the other hand, is a productive process committed to the production of organic and healthy food, ensuring health of human beings. This type of production is adapted to the climate, water, the local reality of soil, topography and biodiversity of the environment, maintaining harmony among the elements and the human beings (Ponisio et al. 2015; Simin and Janković 2014). Organic farming techniques do not use pesticides, which contributes to preserving the quality of water used for irrigation, without polluting the soil and groundwater. This mode of production expands the capacity of local ecosystems to provide environmental services, maintaining soil and water quality, and preserving living systems and environmental biodiversity. Organic agriculture is also aligned with sustainable development and the promotion of family farming, valuing the producer and the surrounding communities (Sutherland and Darnhofer 2012).

Beyond the sustainable production systems, the CSA system also values social issues. The promotion of partnerships and cooperativism are important in the system, favoring the stability and a continuous and planned demand of this system (Opitz et al. 2019). CSA provides farmers with market independence, improved revenues, and risk sharing with consumers. In addition, CSA is a market opportunity for small farmers, who produce on a small scale and with high quality. It is an alternative for those who wish to support themselves by selling differentiated products and avoiding the logic of agricultural commodities, established by the traditional market (Blättel-Mink et al. 2017; Opitz et al. 2017). The reflection of this connection between producers and consumers is the offer of fresh products, with speed and quality, respecting farmers' health, consumers and the production environment.

With regard to the quality of food, this is a critical issue today, as there has been a worsening in the eating habits of the population in recent decades, a fact that reveals the importance of agroecological initiatives such as the CSA (Johns 2020). It is observed today that the computerization process of the food sector facilitates population's access to low nutritional value food (Burlandy et al. 2020; Johns 2020). On the contrary, the consumption of fresh foods, in addition to ensuring people's satiety, is also important for maintaining their health and preventing and controlling diseases such as diabetes, hypertension and obesity (Johns 2020; Moitra et al. 2021). Thus, the CSAs system can fulfill its function of raising the nutritional standard of families.

Access to seals and certifications is also an important point for farmers who are part of CSAs. The search for low-cost certifications, such as the Participatory Guarantee System—SPG, and local certifications can be an interesting solution for CSAs (Hvitsand 2016; Giuliani et al. 2017; Saadun et al. 2018; Maguire-Rajpaul et al. 2020). Some certifications and seals for organic agriculture, such as Biodynamic

Certification, Norton Organic Certificate—IBQ, Fair Trade, UTZ, among others, can also be used for product certification, involving environmental and social aspects.

The products quality assurance can also be established based on the trust between the co-growers and the farmers, through visits and monitoring of production. Trust is the important point for product reliability, so co-farmers trust producers (Blättel-Mink et al. 2017; Opitz et al. 2017, 2019). In the CSA system, co-farmers must also visit the properties and monitor production. This increases confidence, unlike a traditional production system, where consumers are unaware of the origin of the food consumed.

It is important to note that the quality of food is directly related to food security. According to FAO (2021), food security is related to the physical, social and economic access of the population to healthy food in the ideal amount that satisfies the population needs for an active and healthy life.

5 Methods

The scientific research methodology contemplates the application of procedures and techniques that aim at the construction of knowledge, proving its validity and usefulness in different areas of society (Koche 2016; Zangirolami-Raimundo et al. 2018; Kumar 2019). According to Kumar (2019), science corresponds to a systematization of knowledge, that is, a set of correlated propositions of the behavior of certain phenomena of study. Thus, the scientific method refers to the line of reasoning adopted in the scientific construction process, being the result of a set of intellectual and technical procedures applied in the search for knowledge (Koche 2016; Kumar 2019).

Therefore, this study was based on bibliographic research as a technical procedure for obtaining results. According to Kumar (2019), bibliographic research is based on published information, requiring the researcher to check information on the veracity of the data. Thus, three main steps were used in the construction of the work: first, the concept of CSA, its philosophy and the roles of farmers and co-farmers was established; then we presented the CSA's relationship with sustainable agriculture, highlighting the methods of agriculture used in the CSAs; then the research discussions are presented, related to: (i) governance in the CSAs, (ii) empowerment and the benefits of CSA for farmers and (iii) the CSA structure and partners. At the end of the work, a basic CSA model is presented, showing the functioning dynamics and the roles played by farmers, co-farmers and CSA partners.

This work used a survey of information from different sources. As the CSA is a new theme, the research was not limited to bibliographic references in high-impact journals. Several sources of information were consulted: articles in high-impact journals, websites of international institutions related to CSA, publications on the Internet that can contribute to CSA information. International associations related to the CSA were also consulted, through their websites, to identify the structures of the CSAs. By identifying the partners and the structure of the CSAs, it was possible to create a basic CSA model, presented at the end of this work.

According to Zangirolami-Raimundo et al. (2018), an applied research is based on the generation of knowledge for practical application in order to solve specific problems. However, an exploratory research, according to Kumar (2019), aims to promote more information on a specific subject, enabling its definition and delineation. Regarding the research approach, this study presented a qualitative approach. In accordance with Glesne (2016), a qualitative research is characterized by the interpretation of phenomena and the attribution of meanings. Furthermore, according to Glesne (2016), this type of approach does not require the use of statistical analysis techniques.

6 Results and Discussion

The research results and discussions are divided into three axes: the governance of CSAs, empowerment and the benefits of CSA for farmers, and the CSA structure and partners. All discussions are based on bibliographies and information identified in the information survey.

7 The Governance of CSAs

To better understand how CSAs work, it is necessary to understand how they are managed. According to Bhagat and Bolton (2019), governance includes the set of processes, policies, customs, laws and regulations that manage an organization. In this connection, the creation of an organizational culture can be understood as the result of this governance process (Buallay et al. 2017). Thus, talking about the type of hierarchy is fundamental for understanding a specific organizational culture (Bhatt and Bhatt 2017). CSAs can display different types of organizational structure, ranging from the traditional vertical structure to models with a more horizontal structure, with a less rigid hierarchy.

In CSAs, the administration and organization of product distribution are done by co-producers, who act most of the time on a voluntary basis. The food baskets distribution and the contact of new co-farmers or quotaholders are normally done by the members who are in the city. On the other hand, we have producers and farmers, who usually reside on the farms and take care of production. This model stands out as participative and collaborative management, in line with CSA's original philosophy.

The baskets can also be distributed by the producers themselves, so that quota holders have no participation. These CSA models end up functioning as a traditional sales system, where all the work is done by the producer, and the quotaholders act more like customers. According to Madzimure (2019), the distribution logistics of an organization requires planning in both the strategic and financial plan. Thus, logistical planning includes aspects such as transportation management, checking of goods, freight control and management, delivery routing and analysis and monitoring of performance indicators (Madzimure 2019; Khan and Rattanawiboonsom 2020). Thus, in the case of CSAs, a structured model of logistical planning was developed, based on the definition of strategic locations for the distribution of baskets. This reveals members' knowledge of the financial impact of logistical decisions on the CSAs financial health.

In addition, although there is a predominance of the organic hierarchy, in the CSAs assessed the presence of representatives responsible for administrative and financial activities was verified, which in some cases characterizes a mixed hierarchy. This is due to the lack of training of some members, which generates the accumulation of functions in some cases in a restricted group of people.

The flow of information, according to Phornlaphatrachakorn and Na-Kalasindhu (2020), is an important aspect of a smooth organizational activity functioning, as this ensures uniform access to the organization's processes and results. However, when there is no adequate direct or reverse flow of information, the organization creates a production bottleneck, which leads to a waste of resources and, consequently, a drop in productivity (Ansoff et al. 2018; Ferreira et al. 2018; Dzwigol 2020). In this sense, in the CSAs assessed, bottlenecks were observed in some cases in the flow of information and in management processes, even though there was a mixed hierarchy that contributed to the dissemination of knowledge and information. Thus, as a consequence, there are reports of losses of new basket orders due to failure in internal communication in some CSAs.

According to Liu et al. (2018) and Bhagat and Bolton (2019), corporate governance has a direct relationship with the organizations' finance. This is because the financial manager must maintain connections with all other sectors of the organization, in order to collect relevant data for its growth and to provide transparency and flexibility to the setting (Ansoff et al. 2018; Bhagat and Bolton 2019). Therefore the financial sector acts as a precursor of the corporate governance values in the organization (Ansoff et al. 2018). Thus, in the CSAs assessed, there are specific members who act as financial managers, managing the demand for existing baskets, performing the periodic collection of quotas, besides transferring funds for the purchase of production inputs. However, a consistent model of cost management and basket pricing is necessary in almost all the CSAs assessed. In other words, the inexistence of this model hinders the economic transparency of CSAs vis-à-vis their members and limits decision-making regarding adherence to innovative processes, for example.

As to the governance, CSAs must establish a horizontal management. As noted in the survey, CSAs are usually managed by voluntary co-producers, who are responsible for organizing, distributing baskets, publicizing, among other actions within the CSAs. Establishing a strategic planning and establishing participatory governance between farmers and co-producers is also important. The collaboration of local governments, schools, universities, churches, among other institutions is also an important point regarding the governance of CSAs. These institutions, in addition to supporting the administration, should also serve as a way of disseminating the system.

8 Empowerment and the Benefits of CSA for Farmers

The CSA system allows several improvements for farmers. The production forecasting convenience, based on the number of baskets that must be delivered, is one of the positive points. Before using the CSA system, farmers usually sell their products at fairs, generating a lot of product waste. In the sale via the quota system it is possible to predict what will be consumed, often totally reducing the waste of food produced. Sales growth and consequently production growth is also an effect of the CSA system.

A negative point regarding the empowerment of farmers is the setting up of CSA centered on only one or a small number of farmers. This reality can be found in some CSAs, and is not in line with their original philosophy, which is the participation of a large number of farmers, increasing the benefits in a more egalitarian and broader way (Amorim 2018; Matzembachen and Meira 2020; CSA Brasil 2021).

Another CSAs positive point for small farmers is the time autonomy that farmers can enjoy; without this system they are usually responsible for the entire production process until the delivery of food at the points of sale. With the CSA, farmers have the opportunity to better manage the time spent in their field activities, being able to delegate functions to other members and convert this benefit into greater productivity. (Chen et al. 2019; Diekmann and Theuvsen 2019; Savarese et al. 2020).

According to Dolinska and d'Aquino (2016) and Chen et al. (2019), the empowerment of farmers is directly related to innovation processes in the field. In this sense, knowledge is disseminated and formalized in discourses that can be used in the future in individual initiatives (Paul 2019; Chang 2020). Sharing ideas, models and production techniques ensures the success of the farmers' chain and help farmers to achieve better living standards in a shorter time period (Chang 2020; Matzembacher and Meira 2020). Also according to the study by Dolinska and d'Aquino (2016), the importance of interaction among farmers in northwestern Tunisia was observed with the comparison of the individual farmers and the formation of communities.

The interrelationship of CSAs within a given territory is also important for the exchange of information and experiences. CSAs cannot work independently, without cooperation and contact between their officers. The exchange initiatives between the CSAs correspond to an alternative of cooperation both in the productive setting, in the commercialization of food, and in the scientific setting, for the dissemination of events and good production practices (Amorim 2018; Paul 2019; Chang 2020). Thus, the training of members is a positive consequence of this initiative, as many farmers do not have a good planning of which foods to grow, as well as they do not have improved plant growth techniques (Chen et al. 2019; Chang 2020).

Chen et al. (2019) and Matzembacher and Meira (2020) also indicated the importance of including farmers in discussions on education, training, research and agricultural policies, which corresponds to a new milestone for the dynamics of food production. Thus, they start growing food crops with greater wisdom, relating variables such as climate, terrain and soil type, which is essential for responsible production (Amorim 2018; Paul 2019; Chen et al. 2019).

9 The CSA Structure and Partners

The CSA structure is basically formed by farmers and by consumers or co-producers, as they are called in the system. Usually, the co-producers themselves are the intermediaries between the two; they get organized voluntarily to distribute the products and baskets. In some cases this is done by the farmers, but in general it is the responsibility of the co-producers. As the CSA grows, a coordination group is formed, in which their members are responsible for specific functions (e.g. logistics and distribution, dissemination, communication, contact with new co-farmers).

As for partners, CSAs can count on several key partners. The local community is usually the main supporter, using some institution as a support point, such as schools, churches and universities. Many of the CSAs originate from fairs. These fairs usually take place in schools or churches, and from there, the CSA can connect with some institution with facilities to distribute the baskets. The support of NGOs, banks and the local government are also present in CSAs, allowing fundraising to invest in farmers' production.

Some partnerships established with the CSAs do not have a strong involvement of the communities, since in most cases there is only the granting of support points for the distribution of food. In this sense, CSAs should propose communities support programs as a form of dissemination. Such programs would be important both for the expansion of CSAs and for strengthening the existing farmer base.

Another aspect to be highlighted is the process of defining partnerships. Currently, as verified in this study, CSAs do not have an efficient strategic plan for attracting new partners. In view of this, in most cases this process occurs informally through the indication of potential members. Thus, some CSAs face growth difficulties and, consequently, end up grouping a small number of co-growers.

Among the main key partners that make up the CSAs universe we can mention universities, their study centers and development agencies, as well as technology production centers. Other partnerships refer to social movements that advocate agroecology in cities, aimed at urban agriculture, as networks for the expansion and consolidation of CSAs. Schools are also important for CSAs; they function as distribution centers. Therefore, it can be observed that the definition of partners occurs spontaneously and naturally, causing the bonds to be strengthened over time, enhancing relationships.

To illustrate the CSA structure, a systemic model was drawn, presenting the main players, partners and the dynamics of the CSA (Fig. 2).

In this system, it is possible to observe the institutions that support farmers, such as local governments, banks, certification institutions and institutions that support agriculture. Coordination groups should seek support from schools, universities, churches, institutions that can provide support in the dissemination and distribution of products, as well as in CSA centers (CSA Network).

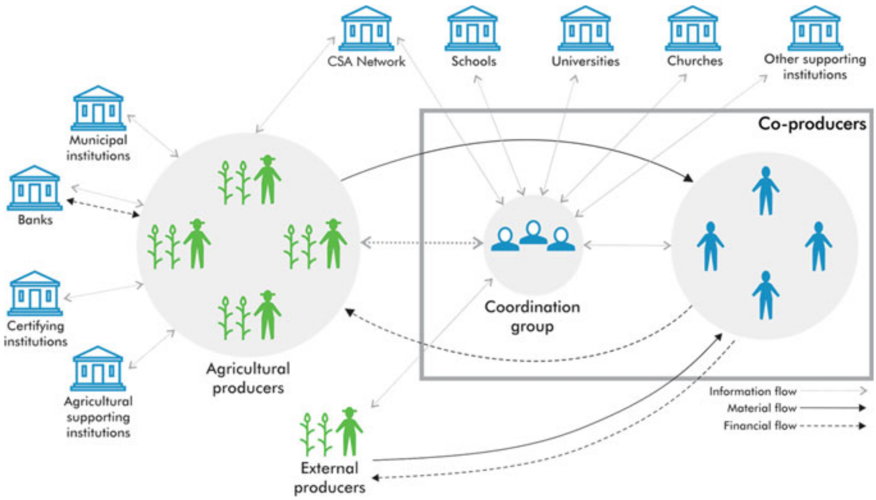

Fig. 2 The structure of CSA and its main partners. *Source* Author

10 Conclusions

In the current situation, the consumption of healthy foods has become one of the priorities in people's lives. On the other hand, small farmers have difficulties in producing in a manner compatible with the stipulated demand, either due to the lack of planning or resources. In this sense, CSAs have emerged as an opportunity for the emancipation of this class of farmers, presenting themselves as an Alternative Food Network (AFN), promoting family farming and improving the income of farmers and their families.

The CSA system introduces a new way of thinking about food production, combining sustainable agriculture, organic production, and a greater responsibility with food production. It is necessary to discuss these topics from the perspective of food security, as the world still needs to develop its food systems in order to create alternative ways of producing and consuming. It is evident that the CSA system helps with food security, operating via a quota system that allows consumption to be forecasted, thus reducing food waste. It is worth remembering the increased visibility of innovative biodynamic production techniques and the greater participation of farmers in their implantation processes as positive results of this movement.

From the perspective of sustainable agriculture, CSA empowers farmers both economically, improving their income, and scientifically, through training in different production processes and techniques. It is important to note that CSAs must be formed with a large number of farmers, aiming at expanding benefits and improving income distribution; CSAs cannot be formed focusing on just one or a small number of producers. CSAs also collaborate for family farming and for the empowerment of female farmers, mothers and daughters, who can contribute to the system through their work in the field and acting as co-producers.

In addition to being aligned with the principles of sustainable agriculture, the CSA system is directly related to the following SDGs of the 2030 United Nations Agenda: No Poverty (SDG 1), Zero Hunger (SDG 2), Good Health and Well-Being (SDG 3), Decent Work and Economic Growth (SDG 8), Reduced Inequalities (SDG 10), Sustainable Cities and Communities (SDG 11), Responsible Consumption and Production (SDG 12), Life on Land (SDG 15), and Partnership for the Goals (SDG 17). Thus CSA can be another alternative for the improvement of food systems, contributing to food security in the world.

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Reducing the Impacts of Climate Change on Agriculture and Food Security in Senegal

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1 Introduction

Senegal is a sahelian country where 70% of the population lives from the agricultural sector. However, this agriculture is highly dependent on climatic factors such as rainfall, temperatures, etc. Thus, in this context of climate change, it is recommended, in accordance with the orientation of the international community (COP21, Paris), to initiate effective adaptation actions for advanced middle-income countries with a high dependence on the agricultural sector. This adaptation to climate change requires an effective scientific approach that addresses all dimensions of resilience of the systems concerned. The complexity of the climate change phenomenon has not facilitated until now the mastery of its real impacts in relation with other related development constraints that limit agricultural productivity.

The main objective of this work is to contribute to scientific research on tools and methods for climate change resilience of development sectors in the Sahel region, in particular, the contribution of local agricultural production to food security in Senegal. The scientific identification of impacts that confirm the vulnerability to climate change of the systems concerned represents a major challenge for the effectiveness and efficiency of resilience activities to be planned. These activities must be differentiated from conventional development actions by their specificity to respond to climate change constraints, which requires rigorous proof that the impact to be reduced by these actions is specifically caused by climate change. Thus, specifically, this paper seeks to propose a scientific approach to identify the impacts of climate variability on local agricultural production in Senegal, on which the national food security strategy is based. Indeed, in the current context, a non-resilient agriculture

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could not achieve the expected socio-economic results. The objective is to propose a scientific approach to develop resilient actions for agricultural production in order to better contribute to national food security.

In this paper, we use an innovative theoretical and methodological approach that is ClimProspect (Badolo 2015). It is unique in that it takes into account the main dimensions of the systems considered and distinguishes the vulnerability of the system from the sensitivity of the context. It is implemented through a participatory and/or scientific approach. Our main hypothesis is the existence of an impact of climate change linked to the state of the agricultural sector itself, on the one hand, and to the various dimensions of the Senegalese context, on the other. This main hypothesis is broken down into two secondary hypotheses:

Hypothesis 1: Food crop production varies with climate variability in Senegal;
Hypothesis 2: GDP varies with national agricultural production in Senegal.

1.1 Definition of the Concept

The most common definition of food security implicitly refers to the four dimensions of food security (FAO): food availability, physical and economic access to food, stability and utilization. "Food security is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (World Food Summit, Rome 1996). It takes into account the socio-economic factors of households but also the political, social, climatic, institutional and economic context of the country. Food security depends on several factors whose congruence makes it particularly complex. However, we can systematically retain that food security rests on a three-level foundation senegal's food security strategy (SNSAR 2015–2035):

The first level is a set of food assistance and nutrition actions that should always be in place to respond to emergencies and could include price-indexed cash transfers.
The second level is constituted by the social safety net, which includes insurance and assistance mechanisms-seasonal public works or employment guarantee systems, insurance indexed to climatic conditions (as in Senegal), management of grain reserves (as instituted by ECOWAS to prevent populations from falling into famine and misery).
The third tier includes measures to promote agriculture-access to land, water, fertilizer, seeds, and financial services-that could be implemented through agricultural development or social protection programs (such as input subsidies).

1.2 Vulnerability and Resilience

Resilience is the ability of a system to cope with or avoid adverse effects of climate change (including climate variability and extremes). Vulnerability depends on the nature, magnitude and rate of climate change, the variability to which the system is exposed, its sensitivity and its adaptive capacity (IPCC 2007). Given a system S in a state or configuration (e) and r a specified risk, the vulnerability or resilience of S to r depends on (e), the state in which S is. The state (e) that a system S is in determines its vulnerability or resilience to a given risk r.

1.3 Agricultural Production and Food Security

For those who hold an orthodox view of the causal link between agricultural production and farm household food security, increasing cereal and animal yields means, and unambiguously, contributing to improving farm household food security (Vall et al. 2017). The challenge is to find sustainable, environmentally friendly, socially and economically accessible ways (Guibert et al. 2016) to achieve sufficient production at the farm level. Finalized agronomic research therefore focuses on these means (technical, organizational or socio-economic, etc.), at the plot, herd, farm, territorial and national levels, to support this production. The objective is to reduce the yield gap, the gap between production potential and realizeď (Affholder et al. 2013), and to invest in public policies to produce enough to cover the food needs of farm households in their diversity (Gérard et al. 2012). Current novelties and specificities concern:

– issues related to climate change, its effects on production and, in turn, the effects of production on climate change
– (bio)technological advances and the revelation of environmental and social problems associated with the Green Revolution (Godfray et al. 2010; Griffon 2006). In short, all contemporary issues related to increasing agricultural production can thus become food security issues when applied to Sub-saharan Africa.

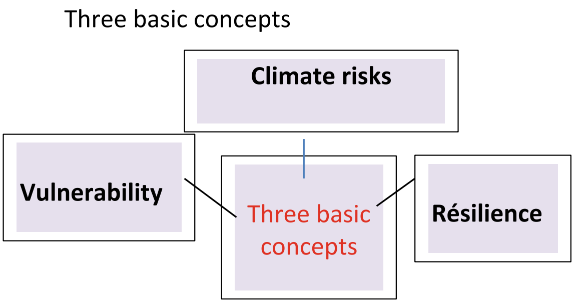
The Government of Senegal, within the framework of its food security policy, has retained as strategic axis 1, "Sustainable improvement of the availability of diversified, healthy and nutritious food" by relying first on local agricultural production: "An effective food security policy must be based on a proper diversification of food production activities capable of reducing the rate of dependence on imports (TDI) and improving the coverage of cereal needs, SNSAR, 2015–2035".

The various concepts of food security described above, and in particular Senegal's National Food Security Strategy, position local agricultural production at a very decisive level of contribution. However, making agriculture in Sahelian countries the main lever for food security in the current climate context is a major challenge.

2 Methods

Three basic concepts

Scheme 1 Of basic concepts. *Source* Author's (2021)



2.1 Characterization of Resilience States

2.1.1 The Scheme 1: Three Basic Concepts

Given a system S in a configuration or state (e), and r a given risk, S is resilient to r, if (e) verifies the equation (Badolo 2015):

r(e) ≈ Ø (no significant damage). In a resilience configuration, there are no impacts; (e) is a resilience configuration or state.

Thus, improving the resilience of the agricultural sector in Senegal and its effective and sustainable contribution to food security must involve rigorous identification of the vulnerability and impacts induced by climate change. To achieve this, we propose the CLIMPROSPECT method.

Let S be a given system, r a given risk;
❑ ev a state of vulnerability of system S with respect to risk r;
❑ er a desired resilience state of system S with respect to risk r;

To transform the state ev into the state ez, we develop a transformer At, which is a resilience operator (state transformer):

Thus, we will have: At (ev) = er; At which the operator that transforms the initial state of the system into another (resilient) state must correspond to resilience projects and programmes (Badolo 2015).
The development of a resilience state must consider both the states ev, er and the operator At;

2.2 Developing the Impact Framework

Impacts are the basic benchmarks for assessing the effectiveness of a system's resilience state.

When a risk r affects a vulnerable entity (e), an impact chain results:

ce = d0, d1, d2, …, dm m is the length of the chain; In an impact chain:

- d0: direct impact of r on S
- d1: indirect impact of order one of r; largest impact of d0
- d2: indirect impact of order two of r; largest impact of d1
- d3: indirect impact of order three of r, largest impact of d2
- d4: fourth-order indirect impact of r, largest impact of d3
- …
- dn: nth order indirect impact of r, largest impact of d(n − 1).

2.3 Impact Characterisation

The direct impact is determined by experience, by the perception of territorial actors and by a literature review.

2.4 Spectrum of n-order Impacts to Determine dn

The spectrum of impacts of order n to determine dn($n \geq 1$) is composed of the direct environmental, social, economic, institutional and political impacts of d(n − 1) on the system studied. The largest impact on the system represents the nth order impact (dn).

2.5 Climate Change Scenarios

When assessing impacts on the agricultural sector, potential future impacts according to climate models should also be taken into account for resilience planning. The climate scenario vector describes the climate profiles used to assess the impacts of future climate change. Two qualitative scenarios are used in this study:

Scenario sc1: This scenario indicates a dry and hot future climate. It predicts a sharp increase in temperature, an increased decrease in rainfall and permanent drought (RCP8.5);

Scenario Sc2: It predicts a future climate that is highly variable compared to the current climate. It is characterised by an increase in temperature and a significant increase in the frequency and intensity of climate shocks (droughts, floods, heat waves) (RCP4.5).

2.6 Impact Baselines

After identifying the different orders of impacts based on the study parameters, which are the system vector e, the risk vector r and the climate scenario vector sc, we can develop impact reference frames, which are the impact tables, the impact spectrum, the socio-economic impact envelopes and the impact families.

The vector e (e1, e2, …, em) is a mathematical analogue of the system studied. The components of (e) are the dimensions of the system under study taken as components in the study.

The components of the climate risk vector r (r1, r2, …, rk) are the climate and disaster risks that recurrently and significantly affect the studied system.

The climate scenario vector (sc) describes the projected climate models used to assess the impacts of climate change in the future.

The first category of impact frameworks: impact chains.

For a component ei of (e) and rj of r, an impact chain is of the form:

$$\text{cij} = \text{eirjd0}, \text{eirjd1}, \ldots, \text{eirjdp}.$$

p is the length of the chain and eirjd0 is the direct impact of rj on ei;

The second category of impact repository: the impact families.

For a climate risk rj, an impact family of order (h) is a vector of the form:

$$\text{frjdh} = (\text{e1rjdh}, \text{e2rjdh}, \ldots, \ \text{ekrjdh}).$$

A family of impacts is composed of the same order impacts of a climate risk on e1, e2, …, ek respectively.

The third category of impact repositories concerns specific impact repositories.

For a risk rj, a specific impact frame of reference drje is the subset of direct and indirect impacts of rj on system S.

The fourth category of impact repository is the global climate risk impact repository, dre. It is the union of all the specific impact repositories.

The fifth category of impact repository is the socio-economic impact envelope:

dre_social = {social type dre elements}.
dre_environmental = {environmental type dre elements}.
dre_economic = {dre economic type elements}.
dre_institutional = {institutional type dre elements}.
political_dre = {political type dre elements}.

3 Results and Discussion

The system vector ea.

In this study, the system vector that will be associated with agriculture is the vector ea of dimension four and formally presented as follows: ea = ea (e1, e2, e3, e4), the four components of the vector ea, corresponding to the mathematical analog for the agricultural sector are:

e1 = National agricultural food production.
e2 = Contribution to the national economy.
e3 = Financing of the agricultural sector.
e4 = Governance of the agricultural sector.

The dimensions of the agricultural sector considered are therefore agricultural food production, contribution to the national economy, agricultural sector financing and agricultural sector governance.

In practice, the impact assessment exercises will focus on each of the components of the ea vector.

3.1 The R-risk Vector

The risk vector R selected for this study is a three-component vector, namely.

r1 = Droughts (precipitation variability).
r2 = Increasing temperature.
r3 = Locust invasions.

These components of the R-risk vector are, by definition, the main climatic and disaster risks that significantly and recurrently affect rainfed agricultural production in Senegal. The identification of these risks was based on the National Action Plan for Adaptation to Climate, the Predicted Contribution Determined at the National Level (CDN approuvée en 2020), data from ANACIM (IPCC focal point in Senegal) and other studies conducted in the country.

3.2 Temperature Increase

There is no doubt that the climate is warming and this is now attested to by the observed increase in average air and ocean temperatures, and the rise in average sea level. For example, the average global surface temperature has increased by +1 °C from 1901 to 2012. The evolution of temperatures.

Africa, particularly the Sahel, is marked by an increase of 0.2–0.8 °C since the late 1970s (Sultan 2015). In Senegal, these trends are observed with alarming predictions:

Current trends: global increase observed especially for minimum temperatures between 1961 and 2010. The data obtained from ANACIM on all these stations of the national territory also confirm this trend of increasing average temperatures in Senegal.

Future trends: forecasts indicate an average variation between +1.17 and 1.41 °C by 2035 (ANACIM).

By 2035, all climate simulations show an increase in average temperature ranging from 0.5 (in the central west) to 1.7 °C in the north-east. Localities in the north-east, central-east and extreme south-east have the highest values. The increase in mean temperature with the RCP8.5 scenario appears to be higher than that of the RCP4.5 scenario in the near to distant future.

Confirmation of the current and future increase in average temperatures over the country therefore poses a risk to agriculture, given the correlation between plant development, particularly of crops, and ambient temperature.

Heat stress is most dangerous for the plant when it occurs during flowering. In rice, heat stress at anthesis prevents anther dehiscence and pollen ejection, which reduces pollination and grain number (Mackill et al. 1982; Zheng and Mackill 1982).

Simulations on rice yields show a 9% decrease per degree increase in mean seasonal temperature (Kropff et al. 1993). For cereal crops, the genotypic variation in thermal requirements for vegetative development is much greater than for reproductive development. As temperatures increase over the long term, grain filling time decreases and it seems unlikely that genetic solutions can be found. In addition, the generally high temperatures and low rainfall on less arable land lead to low biomass production and rapid oxidation. The scarcity of organic matter in turn leads to poor soil structural condition, resulting in a high probability of wind and water erosion. In summary, the confirmed increase in current and future temperatures poses a strong risk to rainfed agriculture because of the very negative consequences for crop development and productivity on the one hand, and because of the negative effects on the soil structure of agricultural land on the other.

3.3 Drought

Drought is defined here as the variability of precipitation leading to unavailability of water for crops in times of need, caused by late or early arrival of precipitation, and its poor distribution in time during the winter season. At the contextual level, climate variability, especially rainfall variability, in West Africa in general and in Senegal in particular, is no longer in question. Variables related to rainfall such as the frequency of rainy days and the length of the rainy season have generally undergone an evolution caused by climate change:

Current trends: The evolution of average rainfall in the four zones from 1951 to 2010 shows a general decline in rainfall from 1951 to 2000 at the reference stations in Senegal, with a trend towards a recovery in rainfall noted between 2000 and 2010. The data obtained in the framework of this work on all ANACIM stations in the country also confirm this trend, with a downward trend between 2010 and 2016.

Future trends: Future trends will generally be downwards towards 2035. The northern part of Senegal will experience a decrease of 16 mm on average compared to the reference period (1976–2005). Elsewhere, the decrease will be more pronounced and will average 89 mm. It should be noted that this decrease is not homogeneous in space and time and some areas could experience more or less significant increases. In fact, this disparity of change across the whole of Senegal and the diversity of the scenarios predicted show the uncertainty that we will have to face.

For the RCP8.5 scenario, on average, there is a decrease in wet periods (consecutive rainy days) and a variability in rainy breaks (consecutive dry days). In particular, there is an increase in extreme precipitation events, especially in the south-east. Precipitation will continue to decrease generally over the whole country, especially in the northwest. This year will therefore be marked by a scarcity of precipitation, while the southwestern region will experience more frequent extreme precipitation events. In general, the models show a trend towards a slight increase in precipitation. In fact, by 2035, the models predict longer dry spells and an increase in the number of days with extreme precipitation. This result shows that with global warming, the winter period will experience more and more rainy breaks (dry sequences) separated by shorter rainy periods with extreme precipitation, as suggested by Giorgi et al. These results are consistent with the 5th IPCC report (IPCC 2014), which explicitly mentions that the level of incidence of extreme climate events such as heat waves, droughts, floods, cyclones and wildfires would result in a high degree of exposure of some ecosystems and many human systems to current climate variability (very high confidence level).

Results from three regional models (RegCM4, CCLM and SMHI) under the RCP4.5 and RCP8.5 scenarios show seasonal changes (June-July-August-September-October: JJASO and December-January-February: DJF) in mean precipitation and selected extreme precipitation events (JJSAO) and temperatures (JJASO and DJF) over the decade 2031–2040 relative to the 1976–2005 normal (baseline period).

As a result, we can expect more frequent occurrences of climate hazards such as droughts, floods and heat waves in parts of Senegal in the future, as well as sea level rise and increased coastal erosion on the coastal fringe.

It is therefore logical to conclude that current and future rainfall remains a high risk for agriculture in Senegal, due to its irregular distribution in time and space, which justifies drought as a lack of water for the plant at times during its development cycle, as a component of the risk vector R in this study.

3.4 Locust Outbreaks

Dry periods are often associated with locust outbreaks. Two major locust (*Schistocerca gregaria*) outbreaks were recorded in Senegal in 1988 and 2004, with hundreds of thousands of hectares of crops infested and significant damage reported. According to the FAO, the 2004 locust invasion affected seven out of eleven regions and caused an average loss of 22% of staple grain production, corresponding to over 45,000 tons and 7 billion CFA francs. Half of the pastures were devastated in the north and about 80% in Diourbel (Lo 2013). In 2004, the combined effects of drought and locust invasion affected the food security of several localities in the country, as well as pastures and the health situation of livestock. This link between drought and the occurrence of locust invasion as a devastating event for agricultural production justifies the choice of this third component of the R-risk vector on the agricultural sector in relation to climate change.

4 Assessment of the Impacts of R on Agriculture

The spectrum of direct and indirect impacts of the risk vector R on the vector ea was developed by implementing the "ClimProspect" tool for each pair (ei, rj), for i = 1, 2, 3, 4, and j = 1, 2, 3. Example: Table 1 illustrates the deployment of this tool for the pair (e1, r1) = (Agricultural food production, drought), according to the impact chain algorithm and for a chain length p, equal to 6.

4.1 Impact Spectra

4.1.1 The Length of the Impact Chain

The length of the impact chain selected being 6, the algorithm allowed for each of the 3 components of the risk vector R, after having determined the direct impact d0 on each component ei, to identify the next most significant indirect impact (d1) among the four types of impact induced (environmental, economic, social, institutional, political) by d0. This iteration produced an overall number of impact chains cij = Σ eirjdp with j = (1, 2, 3) and i = (1, 2, 3, 4), or 12 impact chains.

4.2 Impact Chain Length (p = 6)

The determination of the chain length p was determined by the number of repetitions of the algorithm that reaches the set of the most significant different indirect impacts

Table 1 Impact chain of r1 on e1: (e1,r1)

d0 = food production decrease	Increased pressure on NR	**d1** = deterioration in the supply of cereals to local markets	Increased pressure on NR
	Deterioration in the supply of cereals to local markets increase in the price of food products		Increase in the price of food products
	Increased scale of seasonal movements more		More difficult access to food products
	Increased demands on the Ministry of Commerce, Agriculture		Increased demands on the Ministry of Commerce
	Change in policy priorities		Budgetary difficulties
Dn		dn + 1	
d5 = decreased gross domestic product (GDP)	Decrease in access to the means of agriculture production	d6 = food production decrease	
	Decrease in access to social services		
	Food production decrease		
	Increased difficulties on the ministry of agriculture		
	Change in policy priorities		

Source Author's

that could be triggered from the existence of d0. In this exercise, by reaching the rank p = 6 of the algorithm, we enter a concentric circle and return to the same most significant impacts already identified. It is presented as shown in Fig. 1. Thus, the iteration of the algorithm up to rank 6 has created this loop of impact chains of vector pairs (ei, rj).

5 Impact Families

The number of impact families depends on the length of the impact chain and the dimensions of the risk R. For this study, the risk R (r1, r2, r3) has a component of 3 and the length of the chain is 6, so the number of impact families induced on the

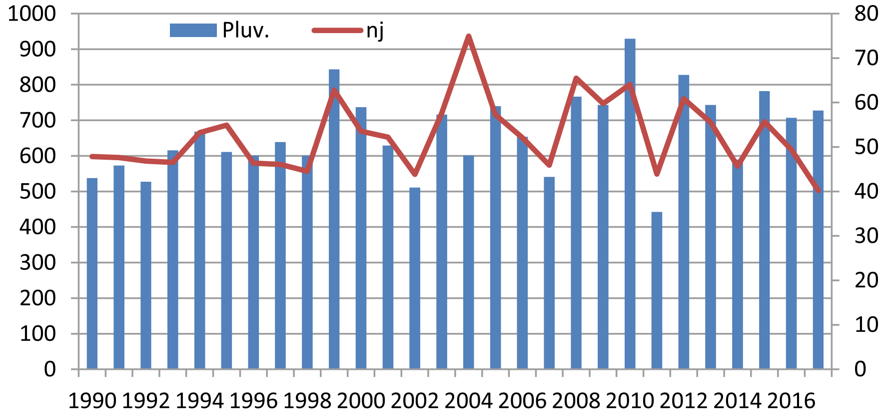


Fig. 1 Average rainfall and number of rainy days. *Source* Author's, ANACIM data

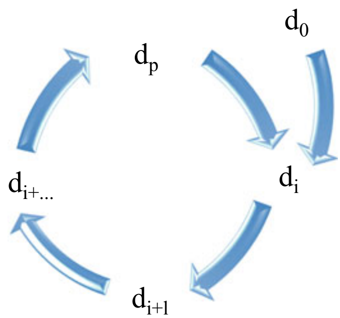


Fig. 2 Loop of an impact chain. *Source* Author's (2021)

vector of e (e1, e2, e3, e4) of dimension 4 is 18. These impact families are subsets whose intersections are not at all empty.

6 Socio-economic Impact Chains

The components of the R-risk vector produced three specific impact chains that can be grouped into five socio-economic subsets: environmental, economic, social, institutional and political. The union (mathematical operation) of these different subsets (impact chains) gives the total direct and indirect impacts of CC on the sector.

By crossing these different sets of impacts, two major macroeconomic elements remain constant: the decline in agricultural food production and the decline in GDP. Moreover, by referring to the country's statistical data, these climate change impacts and the correlation between GDP and agricultural production are confirmed. Figure 3

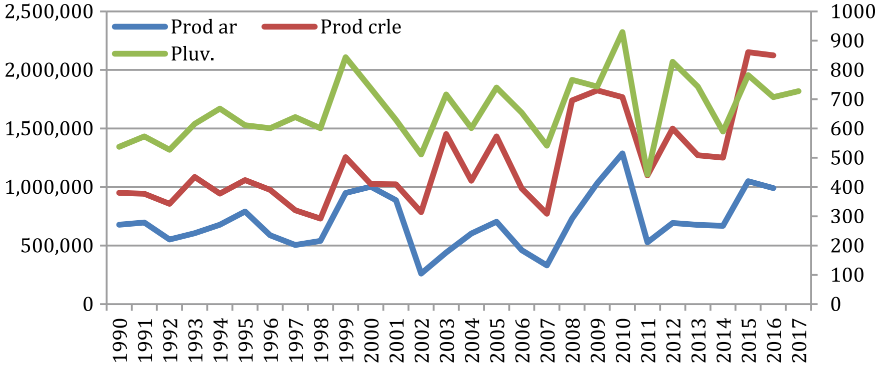


Fig. 3 Correlation of rainfall and agricultural production

shows the correlation between rainfall variability and agricultural production of food and groundnut (the main cash crop).

Figure 4 shows the correlation between agricultural production and gross domestic product. The overall conclusion is that national food production and GDP are vulnerable to climate change and that GDP is correlated with agricultural production. Food security is therefore vulnerable to climate change. The identification of vulnerability factors according to the two main impacts identified (decrease in agricultural food production, decrease in GDP) should allow the development of effective resilience projects and programs for food security in Senegal. The following curve, based on data from the National Agency for Demography and Statistics confirms.

These results confirm our initial hypothesis on agricultural production and GDP in Senegal in relation to climate change. And, referring to the different definitions or

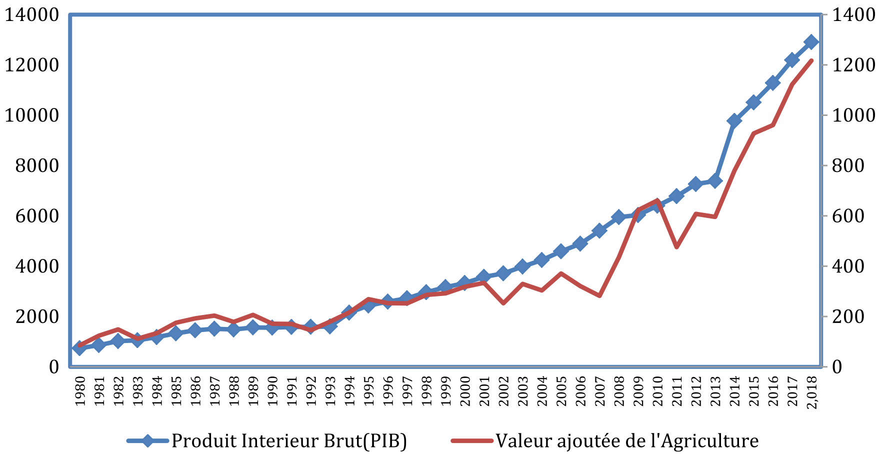


Fig. 4 Correlation curve between agricultural production and GDP. *Source* Author's (2021)

components of food security in the introductory section and to Senegal's Food Security Strategy (SNSAR), the main consequence of the verification of these hypotheses is a decline in food security. The main idea is that food security in Senegal is dependent on the level of resilience of agricultural production.

7 Conclusion

Food security is a major concern of our states, as a characterizing element of socio-economic development but above all of political dependence and stability. Its stable establishment will require a policy of resilience of agricultural production to climate change in Senegal. According to the ClimProsct approach, the aim is to determine the vulnerability factors for the impacts caused by rainfall variability, which are addressed in this study: the multidimensional causes or explanations for the decline in food agriculture production and GDP when rainfall disturbances occur in Senegal. Based on the identification of vulnerability factors, a relevant resilience status of the agricultural sector (project, program) can be developed, in order to make it contribute effectively to food security. It is then important to monitor the evolution of this resilience status based on the residual level of vulnerability factors (vulnerability indicators), the more they disappear, the more effective the resilience to risk is.

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Determinants of Food Access in Raymond Mhlaba Local Municipality, South Africa

Martin Munashe Chari, Leocadia Zhou, Saul Ngarava, and Thulani Ningi

1 Introduction

The ever-rising demand for food globally has been propelled by human population growth and substantial global consumption increases (Tian et al. 2021). Concurrently, the adverse effects of changing climate are jeopardising food security (Kogo et al. 2020). Eradicating hunger in a changing world stipulates that we remain observant in our endeavours to augment food security especially in emerging countries at rural household level (Krishnamurthy et al. 2020). Rural households need more vigilance because they are usually food insecure due to high poverty incidences and their reliance on climatically-sensitive sources of sustenance (Mendelsohn et al. 2007). Although apprehending food insecurity remains a challenge, emergence of phenomena such as climate change, high food prices, and the COVID-19 pandemic points to the need for a better notion of vulnerable households so that effective proactive policies can be designed and implemented to promote sustainable food security interventions (Béné 2020). However, identification of vulnerable households in a specific region requires facts about key determinants of food security (Jaspers and Shoham 1999; Baro and Deubel 2006). These food insecurity apprehensions have

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ignited dialogue among researchers and policymakers on establishing the best ways to boost sustainable food security actions (Brüssow et al. 2017).

Household food insecurity is a global apprehension that has intense effects in developing countries as a result of growing population remaining malnourished (Schleifer and Sun 2020). This is experienced in Asia and Africa, which are hotspots of food insecurity among the developing countries (Lal 2020). The Sustainable Development Goal 2 (SDG2) 2030 Agenda was established to tackle food security under auspices of the United Nations. SDG2 has objectives of ending hunger and ensuring human access to food, particularly those in susceptible situations, by the year 2030 (https://www.un.org/sustainabledevelopment/). Thus, to contribute to meeting the aim of SDG 2, there is a need for constructive food security analysis, which can be partly promoted by continued cautious identification and documentation of determinants of food security in different contexts.

Efforts to address food insecurity require realization of three key categories: how food is made available to people; how they economically and physically access food; and how they utilise the food (WFP 2009). Understanding these influential factors is essential for designing and implementing appropriate and effective food security strategies (Gil et al. 2019). International agencies and stakeholders have developed various tools for assessing household food security to assist in delivering effective plausible interventions for minimizing food insecurity and pointing the most vulnerable groups (Perez-Escamilla et al. 2017). For example, the Comprehensive Food Security and Vulnerability Analysis (CFSVA) is an exclusive instrument that has been developed to comprehend these factors with scenarios from over 27 nations (WFP 2009). The enhancement of food security by identifying determinants of food security is discussed by numerous investigators (Alpízar et al. 2020; Kambanje et al. 2020; Ibukun and Adebayo 2021). Although considerable progress has been made in identifying these determinants, documentation of food security issues in African rural contexts remains limited due to the differing rural geographical contexts (Martin-Shields and Stojetz 2019).

In the African context, South Africa is regarded food secure nationally (Masuku et al. 2017); however, insecure at the household level (Ngema et al. 2018). As part of efforts to boost food security, South Africa's government developed agricultural projects in some vulnerable regions for job creation and income generation (Ngema et al. 2018). Despite these efforts, the Limpopo and the Eastern Cape Provinces remain highly vulnerable to food insecurity due to predominantly rural and high poverty incidences (Ngumbela et al. 2020; Rankoana 2020). To a greater extent, the Eastern Cape is primarily recognised as most susceptible because of its reoccurring droughts (Chari et al. 2021). Although outbreaks have been generally recorded in the Amathole District Municipality (Ndamase 2019), some of the most acute occurrences were experienced within Raymond Mhlaba Local Municipality (RMLM) (Dwesini 2018). In spite of cumulative occurrence of droughts within the municipality, the adoption of productive food security interventions is still in its infancy, and thus remains challenged by limited work such as ascertaining the crucial aspects influencing food security.

This study sought to figure out the determining factors of food security by means of a case study of Mavuso community in RMLM in South Africa's Eastern Cape Province. The study hypothesized that households in Mavuso community are food secure, and that their food security is prejudiced by various socio-economic aspects. The study aimed to provides answers on: (a) What is the extent of food security amongst households of Mavuso community? (b) What aspects are influencing household food security within the community?

2 Conceptualising Food Security

There are four concepts linking food security namely: (1) availability, (2) accessibility, (3) utilisation, and (4) stability, which are observed in different geographic contexts (FAO 2008). Supply-side physical availability of food constitutes food availability (FAO 2008). Hence, availability indicates sourcing of adequate amounts of food of suitable quality, realised through either food aid, importation or own production (FAO 2008). Food access refers to the economic coupled with physical access to existing food and also ownership of adequate resources to acquire proper nutritious foods (Alam et al. 2017). Antagonistic shocks such as price hikes, low income, unemployment, or reduction in livelihood-enhancing assets affect food access. The close association of food security to poverty, socio-economic, and political alienation becomes clearer through the access scope (Barrett and Lentz 2010). Food utilisation comprises various factors that mostly stimulate the consumption of food to the healthiness of people and emphasizes a nutritious vital diet, recognised by foods acquired and conditions positively influencing healthiness (FAO 2008; Labadarios et al. 2011). Lastly, food stability reflects the proneness of the previously mentioned three food security elements. It influences the food security temporal dimension (FAO 2008). Chronic food insecurity is the lack of adequate food over the long-term. This is in contrast to transitory food insecurity, which occurs due to sudden, seasonal, temporal and cyclical disruption (Barrett and Lentz 2010).

The food security notion has directed to inclusive formulation of the access, availability, utilisation, and stability scopes (Qureshi et al. 2015). But, however, due to complexities in the measurement of these four key dimensions, there are numerous methods that are internationally recognised (Jones et al. 2013; Pandey and Bardsley 2019). For this particular investigation, the measurement of household food security was grounded by accessibility, via the HFIAS as applied by similar studies (Mango et al. 2014; Ningi et al. 2021). Furthermore, HFIAS was ideal because it is a subjective rapid rural appraisal method (Pandey and Bardsley 2019), thus matching the location of the study.

3 Methodology

3.1 Description of Study Location and Data Collection

Figure 1 reflects the location of Mavuso community in ward 5 of RMLM, located in Amathole District Municipality in South Africa's Eastern Cape Province. Mavuso community is located 3.6 km away from the nearest Alice town, and 6.5 km from the University of Fort Hare. According to StatsSA (2011), the population of Mavuso community in the 2011 census stood at 1188, with a total area of 0.70 km^2. There are 334 households in Mavuso, with half the population being female, forty-eight percent being below 35 years of age, with 96.88% being Xhosa speaking (StatsSA 2011). There are high unemployment and poverty rates in Raymond Mhlaba Local Municipality at 68% and 71%, respectively (StatsSA 2011). Livestock production is the significant economic activity in the area (Slayi et al. 2014).

A household cross-sectional survey with simple random sampling was utilized in this study. Being centred on a total population of 334 households in Mavuso community (StatsSA 2011), the Yamane (1967) method was utilized to compute sample size:

$$s = \frac{P}{1 + P(i)^2} \tag{1}$$

where s is the sample size, P is the population and i is the confidence interval. The following sample size was then obtained:

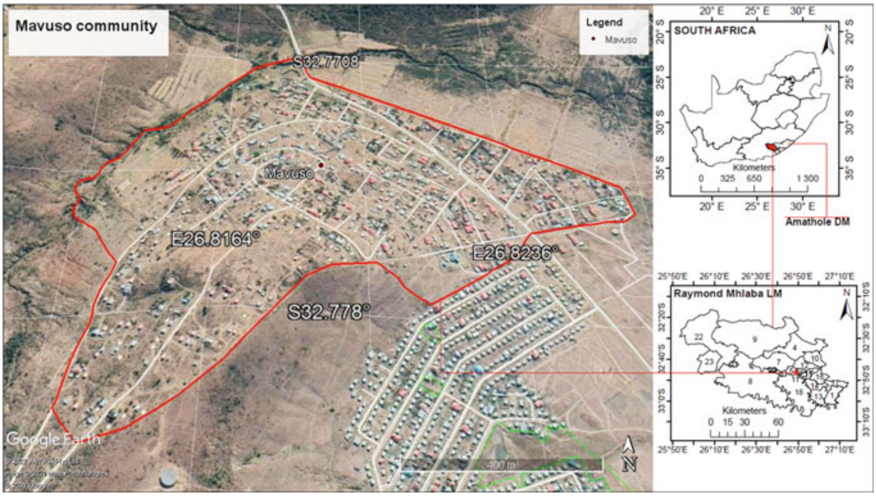

Fig. 1 Geographical setting of Mavuso community. *Source* Adapted from Google Earth

$$s = \frac{334}{1 + 334(0.05)^2} \tag{2}$$

$$s = 182$$

Structured questionnaires aiming at household heads or any persons above 18 years of age were disseminated to 182 households. After cleaning the data, 117 questionnaires were deemed relevant for the analysis.

3.2 Methods

3.2.1 Characterising of Households

The household socio-economic attributes were explained by descriptive information. The factors comprised of age, education status, food aid, number of women 36 and older, number of men 36 and older, wages and salaries, self-employment, farm income, grants, remittances, and food expenditure.

3.2.2 Measuring Food Access by Households

The Household Food Insecurity Access Scale (HFIAS) was utilised in measuring the food insecurity in households (Coates 2004; Coates et al. 2007). The utility of HFIAS allowed testing the hypothesis that households in Mavuso community are food secure. HFIAS is centred on the fact that instances of food insecurity prompt anticipated responses which can be measured and scaled using survey data (Coates et al. 2007). In this investigation, HFIAS was constructed from frequency of occurrence of answers to the HFIAS score questions. The household head or anyone who can answer on behalf of the household head was asked if any of the situations stated in the questions had occurred in their household in the previous month. Regarding the occurrence of the situation, the household head was asked the frequency of occurrence as follows: rarely, sometimes or often. The household was then scaled as follows: 1 (never), 2 (sometimes), and 3 (often). If the HFIAS score was higher then there is high likelihood of food insecurity, and if the response was positive, households were then asked to specify if the event transpired: rarely (1–2), sometimes (3–10), or often (more than ten times) (Carletto et al. 2013).

Basing on guiding principles by Coates et al. (2007), the HFIAS was calculated as:

$$\begin{aligned}\text{HFIAS Score}[0-27] = {} & \mathrm{R}_{1a} + \mathrm{R}_{2a} + \mathrm{R}_{3a} + \mathrm{R}_{4a} \\ & + \mathrm{R}_{5a} + \mathrm{R}_{6a} + \mathrm{R}_{7a} + \mathrm{R}_{8a} + \mathrm{R}_{9}\end{aligned} \tag{3}$$

where R is the response to the occurrence question and the expected score range is 0–27. The HFIAS is an ideal technique because it encompasses all four categories of food security: access, anxiety, insufficient quality, and quantity of food supply (Mango et al. 2014). The study grouped the HFIAS into four ordered categories, guided by the work of Coates et al. (2007), as follows: [0–6] Food secure; [7–13] Mildly food insecure; [14–20] Moderately food insecure; and [21–27] Severely food insecure.

3.2.3 Ascertaining Factors Influencing Food Insecurity

The ordered logit regression model was utilised in order to ascertain determinants of household food insecurity. It was utilized to test hypothesis that food security is prejudiced by various socio-economic aspects. The ordered logit regression model is typically used in estimating the influence of predictor variables on an ordered categorical dependent variable (Williams 2016). For instance, Nata et al. (2014) used the ordered logit regression in addressing the linkages between the embracing of soil quality enhancing practices and food insecurity. Sharaunga et al. (2016) utilised the ordered logit model to determine the aspects of women's empowerment that influence their household food security status. Nkomoki et al. (2019) determined factors that are correlated with food security in Zambian households using the ordered logit regression. This study made use of the HFIAS ordered categories $n = 1$ (food secure: 0–6), $n = 2$ (mildly food insecure: 7–13), $n = 3$ (moderately food insecure: 14–20), $n = 4$ (severely food insecure: 21–27) (Coates et al. 2007) as the dependent variable on the ordered logit regression in order to ascertain the factors inducing the food insecurity in the study area. The following equation illustrates the ordered logit model (Nengovhela et al. 2018; Ningi et al. 2021):

$$Y_j^* = X_j^I \beta + U_{Ij} \tag{4}$$

where Y = HFIAS score ordered as follows:

Y	1 (Food secure households: 0–6)
Y	2 (Mildly food insecure households: 7–13)
Y	3 (Moderately food insecure households: 14–20)
Y	4 (Severely food insecure households: 21–27)
Y^*	given state of household food security;
X_{Ij}	explanatory variables; and
U_{Ij}	disturbance term

Y^* Is unobserved, but the following will be observed;

- Y = 1 if $Y^* \leq \mu_2$;
- Y = 2 if $\mu_2 < Y^* \leq \mu_3$,
- Y = 3 if $\mu_3 < Y^* \leq \mu_4$; and
- Y = 4 if $\mu_4 < Y^*$,

Where μ_x = unknown parameter to be estimated with β based on the cumulative normal function Φ (β'x), the probabilities can be expressed as follows:

- Prob [y = 1: 0–6] = $\Phi(-\beta' x)$;
- Prob [y = 2: 7–13] = $\Phi(\mu_2 - \beta' x) - \Phi(\mu_3 - \beta' x)$,
- Prob [y = 3: 14–20] = $\Phi(\mu_3 - \beta' x) - \Phi(\mu_4 - \beta' x)$; and
- Prob [y = 4: 21–27] = $1 - \Phi(\mu_4 - \beta' x)$.

Where Φ = (the phi co-efficient), is degree of association between two variables (food secure or food insecure).

4 Results and Discussion

4.1 Descriptive Statistics

Table 1 depicts the demographics of the sampled households in the study area. The results reflect that most respondents from sampled households were over 36 years of age with an overall average age of 58 years. Education status of the respondents was relatively high, as the majority (73.4%) had at least secondary education. The distribution of education was as follows: 2 (1.7%) had no formal education, 29 (24.8%) primary, 76 (64.9%) secondary, and 10 (8.5%) tertiary. Many households indicated that they do not receive any food aid (84.7%). Most households had one woman aged 36 years and older (65.0%). Most households had one man aged 36 years and older (59.0%). The majority of households do not receive wages and salaries (69.2%). Most households are not self-employed (77.8%). Most households have no farm income (84.6%). Grants are received by 78.6% of households and 85.5% do not receive any remittances. Most households spend at least R800 per month on food.

4.2 Food Security Conditions and Access Status of Households

Table 2 displays household food security conditions over the last 30 days of reporting. More than half of the households were not capable of eating their preferred food or they sometimes ate food that they did not prefer. Contrary to this, Musemwa et al. (2015) found that less than half of the respondents in Nkonkobe (now Raymond Mhlaba) and Tswane Local Municipalities sometimes ate food they did not want. The differences can be attributed to the additional study area that could have had a larger proportion of food secure respondents, thereby reducing the number of households that ate unpreferred food. It is also interesting to note that 8.7% of the households often purchased food on credit, whilst 7.8% often worried about not having food. Grobler (2014) found that a quarter of family circles in a deprived neighbourhood

Table 1 Characteristics of households

Variable		Frequency	Percentage
Education status	No formal education	2	1.7
	Primary	29	24.8
	Secondary	76	64.9
	Tertiary	10	8.5
Receive food aid	Yes	18	15.4
	No	99	84.7
Number of women 36 and older	0	13	11.1
	1	76	65.0
	2	21	17.9
	3	7	6.0
Number of men 36 and older	0	36	30.8
	1	69	59.0
	2	8	6.8
	3	4	3.4
Wage and salary	Yes	36	30.8
	No	81	69.2
Self-employment	Yes	26	22.2
	No	91	77.8
Farm income	Yes	18	15.4
	No	99	84.6
Grants	Yes	92	78.6
	No	25	21.4
Remittance	Yes	17	14.5
	No	100	85.5
Food expenditure	R(0–200)	2	1.7
	R(201–400)	1	0.8
	R(401–600)	11	9.4
	R(601–800)	12	10.2
	R(801–1000)	34	29.1
	R(1001–1200)	31	26.5
	R(1200) and over	26	22.2
	Min	*Max*	*Mean*
Age	25	103	58.4

Source Authors own

Table 2 Food security conditions experienced by households over past thirty days

In the past thirty days, has the household …	%			
	At no time	Seldomly	Occasionally	Often
Worried about not having food	27.0	22.6	42.6	7.8
Not able to eat preferred food	23.5	18.3	53.0	5.2
Eat limited or smaller	43.5	27.8	24.3	4.3
Eat un-preferred	27.0	15.7	53.0	4.3
Eat small	35.7	25.2	36.5	2.6
Eat fewer	40.9	27.8	27.8	3.5
Had no food at all	73.0	12.2	12.2	2.6
Slept hungry	73.0	13.9	11.3	1.7
Spent whole day without eating	73.0	13.0	12.2	1.7
Borrowed food	47.8	20.9	30.4	0.9
Purchased food on credit	47.0	16.5	27.8	8.7
Gathered wild fruits	70.4	13.9	13.0	2.6
Consumed seed stock	59.1	17.4	20.0	3.5
Sent member to eat somewhere	82.6	4.3	9.6	3.5
Sent member to beg	81.7	11.3	6,1	0.9

Source Authors own

in South Africa purchased on credit at least twice a week. The differences can be attributed to the income and poverty level differences between the current study and Grobler's (2014) study. The current study was in a rural community with fewer employment sources and thus eligibility for credit. Overall, the majority of the households never sent their household members to eat somewhere (82.6%) and never sent a household member to beg for food (81.7%). Furthermore, 73.0% of the households would never have no food at all, sleep hungry or spend whole day without having any food. The findings are also similar to Grobler (2014) who identified that 71.2% of households never skipped a meal and 68.1% of households never relied on help from a relative or friend and never borrowed.

Table 3 shows results from the HFIAS articulated in the study area. The mainstream of households from Mavuso community were food secure (40.2%). However,

Table 3 HFIAS in Mavuso community

Scale	Frequency	Percentage (%)
Food secure	47	40.2
Mildly food insecure	50	42.7
Moderately food insecure	18	15.4
Severely food insecure	2	1.7
Total	117	100

Source Authors own

1.7% were severely food insecure, whilst 15.4% and 42.7% were deemed moderately and mildly food secure, respectively. The study rejects the null hypothesis of no food security, highlighting that there is a degree of food security. This is in contrast to Musemwa et al. (2015) who identified that in the Nkonkobe (now Raymond Mhlaba) Local Municipality most households (68.0%) were severely food insecure, whilst 24%, 4% and 4% were moderately, mildly and food secure, respectively. This can be explicated by previous food security agricultural projects implemented by the government within the location of study area as a mode of employment creation and household income generation.

The results indicate that a large percentage households were mostly food secure. Joshi and Raghuvanshi (2020) observed related results pointing out that the mainstream of rural households are moderately food insecure. This portrays that the problem for food security might not be access (Ningi et al. 2021).

4.3 *The Determinants of Food Insecurity in Mavuso*

Table 4 illustrates outcomes of factors affecting food security of households in the study area using an ordered logit model. Various researchers applied different approaches for the analysing aspects affecting food security, but most have utilised

Table 4 Logit regression model results on aspects influencing state of food security

Variables	Coefficient	Std. Error	Sig. (*p*)
Age	−0.049	0.021	0.018**
Male head responsible for cooking	1.183	0.857	0.167
Female head responsible for cooking	0.640	0.566	0.258
Number of women 36 and older	0.352	0.370	0.342
Number of men 36 and older	−0.401	0.337	0.234
Highest education of person earning most income	−0.475	0.182	0.009***
Receive food aid	0.551	0.665	0.408
Grow garden crops or vegetables	1.385	0.699	0.048**
Maize production in past 12 months	−0.704	0.612	0.250
Distance from water source	−0.275	0.253	0.278
Do you pay for water	1.598	1.475	0.279
Remittances	−1.998	0.797	0.012**
Used indigenous knowledge (IK) methods before	−2.706	0.948	0.004***
Nagelkerke R^2			34%
χ^2 *statistic*			25.37
χ^2 *based on the deviance*			0.021

Significant at ***(1%), and **(5%) levels respectively
Source Authors own

the ordered logit regression technique (Tiwasing et al. 2018; Sani and Kemaw 2019; Ibukun and Adebayo 2021) due to the nature of the data. The Pseudo R-squared (R^2) was calculated to determine the coefficient of determination. The Nagelkerke R^2 (34%) indicated that some of the variations explained the model. The goodness of fit test also reflected that data and model predictions were aligned to those supported by large significant values (Pearson's chi-square statistic = 25.37; Chi-square statistic due to deviance = Sig. 0.021). The study found that age, education levels, garden production, remittances and utilisation of indigenous knowledge in weather forecast were significant factors affecting food security. The null hypothesis of no socio-economic factors affecting food security is therefore rejected.

Household heads' age showed a negative association with HFIAS. The outcomes show that a unit increase in household heads' age is associated with −0.049 decrease on the log odds of the HFIAS, retaining all other independent variables constant. Generally, the results imply that older household heads are more food secure than households with younger household heads. This could be explained by the limited employment prospects for youths and older people are receiving old age grants to supplement their food security in rural areas. These results are in line with Sekhampu (2013) who claimed that as the household head ages, their food security improves. Several other studies attest that as the household head in rural communities ages, their food security improves (Arene and Anyaeji 2010; Bashir et al. 2012; Musemwa et al. 2015).

The highest educated household head earning the most income is negatively associated with the HFIAS. The results imply that a unit increased in the education level of the household head is associated with −0.009 decrease on the log odds of the HFIAS, holding other predictors constant. The results further indicate that households with an educated household head earning more income are less prone to food insecurity cases compared to households with heads that have lower levels of education and earn less income. This implies that the higher the education levels in a household, the more the food security. Similar results were revealed by Kara and Kithu (2020) in assessing education achievement by household heads and household food security in Yatta sub-county of Kenya. The findings reflected a positive relationship between education achievement by the household head and household food security status (Kara and Kithu 2020). Musemwa et al. (2015) had similar results in a study that was carried out in Nkonkobe (now Raymond Mhlaba) and Tswane Local Municipalities.

Growing garden vegetables had a positive association with the HFIAS. The results indicate that an increase in households' participation in vegetable gardening is related to a 1.385 increase on the HFIAS, holding all other predator variables constant. The results imply that when households participate in vegetable gardening, food insecurity increases compared to those ones who do not participate. This is in contrast with Baiyegunhi and Makwangudze's (2014) finding of home-gardens improving the food security status of HIV/AIDS affected households in KwaZulu-Natal Province. The difference might be due to the peculiar differences in the health status of the households, where in the current study this aspect was not considered. The results might also be explained by the fact that households involved in vegetable gardening have less time for other activities such as looking for work and improving their income since most food items are sold in markets.

Receiving remittances had a negative relationship with HFIAS. The results indicate that an increase in receiving remittances is associated with −1.998 decreases the HFIAS, holding all other independent variables constant. The results also indicate that households who receive remittances are more food secure than those who do not. In a study in Sekhukhune District in South Africa, Masekoameng (2015) also found that excessive dependence on remittances was a significant factor of food security. This could be explained by the fact that most households receive social grants, and remittances act as a supplement to their income in rural areas.

The use of indigenous knowledge methods had a negative connection with the HFIAS. The results indicate that growth in household numbers using IK methods to forecast weather is associated with −2.706 decreases on the HFIAS, holding all other independent variables constant. The results also indicate that when households use IK-based methods to forecast weather, their food security status improves and they are more food secure than those who do. Masekoameng and Molotja (2019) and Nyeleka not use them et al. (2019a, b) acknowledge that indigenous knowledge systems are significant in improving household security in South Africa. The study outcomes could be explained by the notion that households who use methods to forecast the weather are more aware of the implication of the climate for their food production; therefore, they prepare their coping strategies in advance.

5 Conclusion

The study aimed to ascertain significant influences of status of food security amongst the rural households in RMLM of South Africa. The HFIAS and an ordered logit model were applied to the household survey. The results revealed that most of the respondents were the elderly and had attended at least secondary education. Most of the households were food secure and key factors that influence household food security status are age, education status, food gardening, indigenous knowledge, and remittances. The null hypotheses of no food security and no socio-economic factors affecting food security were rejected. The study therefore concludes that, at the time the study was conducted, there was food security and there were various socio-economic factors that affected this food security. The study recommends that households be more educated about the significance of knowledge and its part in elevating sustainable livelihoods. Furthermore, advancing programmes supporting household food gardening could make a positive difference coupled with the use of indigenous knowledge.

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Conflicts of Interest
No conflicts of interest arose from this study.

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Coping Strategies and Determinants of Food Availability Amid Climate Change in Rural Communities of Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa

Thulani Ningi, Leocadia Zhou, Saul Ngarava, Martin Munashe Chari, and Patrick Nyambo

1 Introduction

Food availability is when the quantity and quality of available food can sufficiently sustain people's livelihoods at the national and household level (Dodd and Nyabvudzi 2014). Availability of food in most rural households is heavily dependent on agriculture and plays a crucial part in ensuring household food security. Farming remains one of the activities conducted in rural areas that significantly contribute to food security and income generation (Karbasi and Sayyadi 2016). However, agricultural production is being negatively impacted by the persistent global climate variability (FAO 2021). Climate change is reported to increase variability in rainfall and intensification of drought and floods incidences (Nciizah et al. 2021). Climate change continues to be a constant constraint for food availability through its impact on household crops and animal production (Wollenberg et al. 2016). Rural households in less developed countries are more at risk because of their low adaptive capacity, which results in cereal crop yields of less than one ton per hectare (Schmidhuber and Tubiello 2007; Firdaus et al. 2019; Nciizah et al. 2021). In addition, climate change leads to increased livestock mortality due to water shortages, increased disease and heat stress, and compromised feed crops' availability and quality of forages (Escarcha

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et al. 2018). Households' food availability is further worsened by their low financial stability, which leaves them unable to buy enough quality food to supplement the low crop yields (FAO 2021). In order to improve food insecurity in developing countries, sustainability performance needs to adapt and cope with climate change (FAO 2021).

The sustainable development agenda (SDG) of 2030, particularly (SDG)-2, stresses the importance of eradicating hunger while achieving food security and promoting nutritious diets (FAO 2021). However, it is challenging to achieve food security since agriculture competes with other industries for limited resources such as water, labour and land (FAO 2016b). Moreover, the high land degradation rates have resulted in the loss (soil erosion) of about 10 million hectares of productive land (FAO 2021). Da Cunha et al. (2014) attested that climate change negatively affects the farming industry by reducing the soil moisture content. Consequently, premature drying of grains occurs, faster depletion of the soil water and increased heat stress lowers food production (Karmakar et al. 2016), thus increasing the level of food unavailability and limited access for rural households.

Most households in rural areas lack access to inputs, knowledge, marketplaces, and certain ownership of land rights and resources, more especially women (FAO 2021). This trend has then indicated social inequality in food security for developing countries. According to FAO (2016a), collateral influences caused by modern agricultural production influence past development approaches and have caused sustainability to be one of the crucial goals pushed forward by sustainable development. Rendering Intergovernmental Panel on Climate Change (IPCC) (2014), the changing climate is expected to impact food security depending on the particular region in developing countries. Some countries are projected to have high temperatures and precipitation variability, while others are expected to have prolonged drought and water scarcity (IPCC 2014; FAO 2021). Climate change significantly influences crop and livestock production in developing communities, as most small-scale farmers solely depend on rainfed agriculture (Mekonnen et al. 2021; Endalew et al. 2015). Several scholars have stressed that climate change forces production to decline by reducing the yield and available food, causing food insecurity for households (Weldearegay and Tedla 2018; Mekonnen et al. 2021). Furthermore, literature has indicated that temperature increases and precipitation reduction caused by the changing climate reduce crop production (Alemu and Mengistu 2019). Predictions from the IPCC (2014) indicate that there will be an increase in temperature from 1.5 to 2.5 °C, which will lower plant and animal production by about 20–30%, causing the extinction of species, therefore, causing severe consequences to food security in less developed communities (Mekuria and Mekonnen 2018).

Most rural households depend on indigenous knowledge to adapt and cope with climate change-induced shocks (Mongi et al. 2010). Akinnagbe and Irohibe (2015) argued that developing countries in sub-Saharan Africa are more vulnerable to climate change, mainly because of the region's geographical position and climate condition, weak adaptive capacity, high dependence on agriculture, and limited knowledge. Furthermore, the region will face about a ten to twenty million loss in hectares on available land for double-crop production and about 5–10 million of triple yield production induced by climate change (Schmidhuber and Tubiello 2007;

Fischer et al. 2005). The projected changes have negative implications for social and economic performance, resulting in food insecurity (FAO 2021).

At the national scale, South Africa is perceived to have enough food, in terms of food availability (Masipa 2016). However, several scholars have argued that South Africa is far from food security (Hart et al. 2009; Mkhawani et al. 2016; Ningi et al. 2021). To respond to food security issues, the Department of Agriculture Forestry and Fisheries (2013) has developed farming programmes seeking to generate emplyment and assist households in generating income (Hart et al. 2009). However, StatsSA (2011) has indicated that about 4.75 million South Africans still live under the poverty-line. The impact of climate change on food security in South Africa is recognised as one of the major concerns (Masipa 2016). Aliber and Hart (2009) have stressed that even though South Africa is food secure at the national level, some households live under food insecurity which is caused by by climate change related insidents since most households depend on farming for their food availability and access.

Several scholars have stressed the impact of the changing climate on food security in the Eastern Cape Province (Ngumbela et al. 2020; Zhou et al. 2016; Africa 2012). However, limited studies have tried to assess the direct coping strategies household can use to adapt and cope with climate change in their quest to achieve sustainable food availability. Several scholars have stressed the need for the availability of food for rural households in the Raymond Mhlaba Municipality (Musemwa 2013; Dodd and Nyabvudzi 2014; Ningi et al. 2021). However, limited studies have attempted to investigate coping strategies in the Eastern Cape Province, particularly in rural settings where most households are dependent on food gardening to supplement their purchased food. Therefore, this study hypothesised that rural households lack direct coping strategies aimed at climate change shocks, which negatively impact their food availability, and that several socio-economic and institutional factors determine thier food availability status. We test this hypothesis rigorously in our chapter by drawing from evidence from a cross-sectional survey conducted in the Mavuso location in the Raymond Mhlaba Local Municipality. This study aimed to fill the gap by providing information about the drivers and coping strategies used by households in rural settings to meet their food availability in times of climate change.

2 Conceptual Framework: Sustainable Livelihood Approach

In this study the Sustainable Livelihood Framework (SLF) approach is utilised to investigate food security in the face of climate change because it includes environmental issues, which have a significant contribution to rural development (Ashley and Carney 1999). According to Dharmasena et al. (2016) socio-economic and environmental issues play a vital role in driving food availability amid climate change

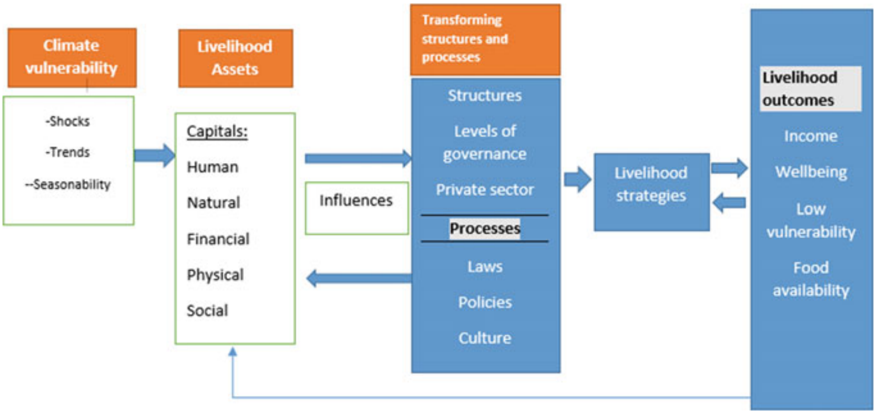

Fig. 1 Sustainable livelihoods framework. *Source* Adopted from DFID (1999)

induced incidents. The framework also illustrates that the choice of livelihood strategies used by households also influences their income and food security (Wright et al. 2012) through the availability of food resources. According to Wright et al. (2012), the quantity of food available can also influence the choices of livelihood strategies households use to cope with vulnerabilities such as climate change. Hence, this study sought to investigate food availability amid climate change in rural communities.

This study adopted the SLF to help understand drivers of food availability amid climate change. The framework is mainly used to assist in understanding the livelihoods of the underprivileged and to sustain their wellbeing more especially under shocks driven by climate change (Ashley and Carney 1999). Donohue and Biggs (2015) attested that the framework helps understand factors and movement under shocks, which might contribute to the deprivation of the underprivileged in improving their livelihoods. According to Wright et al. (2012), the framework claims that the vulnerability context directly influences households' status and livelihood choices. Hence, climate change is conceptualised as one of the features considered in vulnerability. Furthermore, to achieve sustainability in the livelihoods of the poor, households must be in a position to cope with unexpected shocks such as climate change imposed by the environment and maintain assets while considering natural resources such as food (Scoones 2009). The framework is focused on the household scale and assets controlled by the household, which might be influenced by external factors and shocks such as drought and the changing climate (Scoones 1998).

Coping with climate change is mainly related to agricultural development initiatives conducted by households in rural areas (Connolly-Boutin and Smit 2016). Furthermore, According to Connolly-Boutin and Smit (2016) climate change vulnerability and coping strategies are connected to food security (availability), including sustainable livelihoods. Hence, the IPCC identified a connection between coping strategies and sustainable development (Yohe and Strzepek 2007), especially concerning rural household food availability. Figure 1 summarises the sustainable livelihoods approach (DFID 1999).

It has been recognised that climate change is one of the acting stressors to households' livelihoods strategies. The capacity that household to be food secure is influenced by a number of economical, institutional and social conditions (Connolly-Boutin and Smit 2016). As indicted in Chambers and Conway (1992), households' livelihoods are driven by the following capitals: social, physical, financial (income), natural (food), and human (labour) capital.

> Social capital is defined as; the relations and networks that enable people to co-operate. In comparison, human capital is the skills and ability people use to pursue different livelihood strategies, while natural capital is the natural resources people use to sustain their lives. Physical capital is mainly the essential infrastructure humans depend on for their livelihoods, such as water supply and sanitation. Financial capital is the availability of stocks, including savings, wage income, and pension (Martens 2015:9).

When building their livelihoods, households have to respond to several stressors which impact their food availability, of which climate-related shocks may not be ignored (Connolly-Boutin and Smit 2016). This study hypothesis that rural household have no means of coping with shocks and their food availability is by institutional, socio-economic and geographic factors. Food availability is the most crucial measure of sustainability for households' wellbeing to maintain their livelihood. Hence, this study sought to adopt the SLF to connect socio-economic factors influencing availability to food in the face of climate change assess the coping strategies used by households amid climate change shocks. In achieving this goal, the chapter describes food availability for households and presents drivers amid climate change.

3 Materials and Methods

The study was carried out in Mavuso village in Raymond Mhlaba. Raymond Mhlaba Local Municipality, which was previously known as Nkonkobe Local Municipality was established in 2016 and is fomulated of the dissembled local council (Local Government Handbook 2016). The municipality is the second-largest among the local municipalities in the Amatole District Municipality in the Eastern Cape Province of South Africa. Numerous scholars have found the Municipality to have high levels of unemployment (Zhou et al. 2016; Dodd and Nyabvudzi 2014) (Fig. 2).

Mavuso village is located 3.6 km away from Alice, which is the nearest town, and 6.5 km from the University of Fort Hare. According to StatsSA (2011), the population of Mavuso village in the 2011 census was 1,188, with a total area of 0.70 km^2. There are approximately 334 households in Mavuso, with half the population being female. Forty-eight percent of the population in Mavuso is under 35 years old, with 96.88% being Xhosa speaking (StatsSA 2011). There are high unemployment and poverty rates in Raymond Mhlaba Local Municipality at 68 and 71%. Livestock production is a significant economic activity (Musemwa et al. 2018).

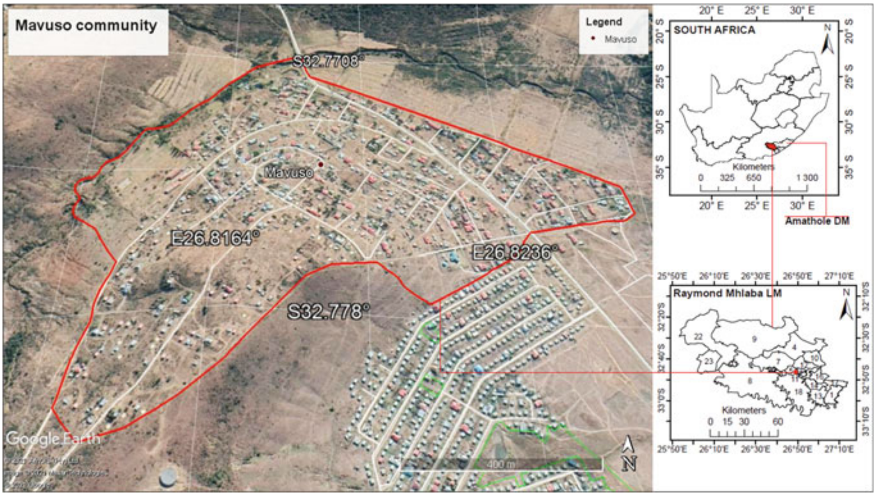

Fig. 2 Study area map. *Source* Google Maps

3.1 Sampling Process

The study utilised a household cross-sectional survey. Simple random sampling was utilised in the study. From a total population of 334 households in Mavuso village (StatsSA 2011), Israel's (2013) method was utilised to calculate the sample size as specified in Ningi et al. (2020):

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

where n is the sample size, N is the population, and e is the confidence interval. The following sample size was then obtained

$$n = \frac{334}{1 + 334(0.05)^2}$$
$$n = 182 \tag{2}$$

A structured questionnaire was distributed to 182 households targeting the household head or any other person who could answer on behalf of the household head. However, after data cleaning, only 117 questionnaires were eligible for further analysis.

3.2 Data Collection

Data was collected through a structured questionnaire. The questionnaire entailed information on demographic characteristics of the surveyed households and their vulnerability to climate change-related disasters based on the five livelihood capital assets: human, social, physical, and natural. The questionnaire included information about food availability at the household level.

3.3 Data Analysis

Data from 117 households was deemed helpful for analysis after 65 questionnaires had been discarded. Based on the research requirements, descriptive, inferential statistics and an econometric model were applied for analysis. The statistical analysis was carried out using SPSS version 26. Applying descriptive statistics, frequencies, mean, maximum, minimum, and percentages were used to present the results. The Household Food Consumption Score (HFCS) was used to measure food availability. The binary logit was used to investigate the factors driving food availability.

3.4 Measuring Food Availability

The household food availability was measured using the HFCS developed by the World Food Programme (WFP) in 1996. The score is based on the food consumed by the household for seven days. The score is then weighted based on the relative nutritional value consumed in the specific food group. The score is then developed based on the eight consumed food groups: starches, pulses, vegetables, fruits, meat, dairy, fats, and sugar. The consumption frequencies are then summed up and multiplied by their specific food group weight. The higher the consumption score, the higher the household's food availability (Weismann et al. 2009; Coates et al. 2007).

The HFCS is calculated as follows:

$$\begin{aligned} \text{HFCS} &= (\text{starches X } 2) + (\text{ pulses X } 3) + (\text{ vegetable}) + (\text{Fruits}) + (\text{meat X } 4) \\ &= (\text{dairyX4}) + ((\text{fats X } 0.5) + (\text{sugar X } 0.5) \end{aligned}$$

The expected score is a continuous variable. The higher the score the better the chances of the household being food secure and food is available to them. The study categorised the HFSC into two ordered groups as defined below:

(1) HFCS 0–21 Low food availability.
(2) HFCS 21.5 and above High food availability.

3.5 Factors Influencing Food Availability

The study also used the binary logit regression model to investigate the determinants of food availability. The study made use of the HFCS which was categorised into $n = 0$ (low food availability: 0–21), $n = 1$ (high food availability: above 21) as the dependent variable on the binary logit regression in order to determine the determinants of food availability. The following equation illustrates the binary logistic model:

$$Z_i = þ_\mu + \sum(\beta_{iXki}) \quad (3)$$

Where X_i represents a set of parameters that determine the i th household's food availability status. Z_i is the odds of a household having food available or not, a dichotomous dependent variable is coded as 0 for poor food availability and 1 for an acceptable food availability status. β_0 represents the model intercept and β_1 to β_i represent the coefficients of the explanatory variables, X_1 to X_{ki}.

$$P_i = \frac{e^{Z_i}}{1 + e^{Z_i}} \quad (4)$$

where P_i denotes the likelihood of the ith household food availability status being acceptable and $(1 - P_i)$ is the likelihood of the household having poor food availability. The odds (Y = 1 against the Y = 0) define the proportion of the likelihood of a household having an acceptable food availability (P_i) to the likelihood of being $(1 - P_i)$; that is, odds $= e_i/(1 - P_i)$. Using the natural logarithm, the prediction is portrayed in the following equation;

$$L_i = \text{In}\left(\frac{P_i}{1 - P_i}\right) = Z_i \quad (5)$$

whereby the value of:

$$P_i = \left(\frac{1}{1 - e^{-Z_i}}\right) \quad (6)$$

Z_i is also denoted as the logarithm of the odds ratio in relation to a household having food available, as portrayed in the regression equation:

$$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \ldots \beta_n X_n + u_i \quad (7)$$

where Z_i represents the household food availability status indicated by 1 for acceptable food availability and 0 for poor food availability, β_0 is the victor of the unknown parameter (intercept), and μ_i denotes the error term.

4 Results and Discussion

4.1 General Overview of Socio-Economic Characteristics of the Respondents

The socio-economic characteristics of the surveyed households are presented in Table 1.

The results illustrate that the most of the respondents had a secondary education (64.9) followed by primary education (24.8% with a minority having tertiary education (8.5%). Most households in the communities spend more than R 800 on food expenses (29.1%). The majority of the respondents have resided in the same location for their lifetime (70.9%). The average age of the respondents was 58 years, with the oldest respondent being 103 years of age.

Table 1 Socio-economic characteristics of the surveyed households

Variable	Category	Frequency	Percentage	
Education status	No education	2	1.7%	
	Primary (grade 1–7)	29	24.8%	
	Secondary (grade 8–12)	76	64.9%	
	Tertiary (cert, dip, degr etc.)	10	8.5%	
Food expenses	R0-R200	2	1.7%	
	R201-R400	1	0.8%	
	R401-R600	11	9.4%	
	R601-R800	12	10.2%	
	R801-R1000	34	29.1%	
	R1001-R1200	31	26.5%	
	More than R1200	25	21.4%	
Years of residence	0–5 years	5	4.8%	
	6–10 years	3	2.6%	
	11–15 years	1	0.9%	
	15–20 years	7	5.9	
	21–30 years	14	11.9	
	Lifetime	83	70.9%	
	Min	*Max*	*Ave*	*SD*
Age	25	103	58	14.03

Source Authors work

Table 2 Household food availability status

Food availability status	Frequency	Percentage (%)
High availability	89	76.1
Low availability	28	23.9
Total	117	100

Source Authors work

4.2 Household Food Availability Statuses

Table 2 presents results from the household food availability status.

From the results it is evident that the most of households had high food availability (76.1%), with the minority having low food availability (23.9%), respectively. Similar findings were observed in Ngema et al. (2018), who showed that due to ownership and participation in food gardening, the availability of food sources for households increases compared to those without. Cheteni et al. (2020) indicated that households participating in food programmes usually have more food available for their home consumption than those who are not involved.

4.3 Experiences of Climate Change-Induced Shocks by the Surveyed Households

Table 3 indicates that most households have heard about climate change and how it impacts on crop yield (82.1%). The respondents also perceived that climate change is the cause of low rainfall (36.7%) and drought (30.8%), which negatively affect their food production. The majority of the surveyed households have never received training on climate change (89.7%). Most of the respondents had not used indigenous methods to focus on the weather (47.9%). At the same time, 47.9% of the respondents claimed that they had been affected by climate change in the previous years, which negatively influenced food production. The majority of the surveyed households indicated that they have experienced climate shocks such as drought (79.5%); 43.5% stated that low rainfall caused massive damage, which lowered their maize yield; 24.8% indicated that they had lost their livestock because of drought. At the same time, 27.4% claimed that they had lost crops due to drought. A similar finding was observed by Mekonnen et al. (2021) who posited that most households have heard about climate change; however, most were not informed about adaptation and coping strategies on climate change shocks. Mdoda (2020) indicated that climate change shocks in the study areas negatively affected the agriculture productivity by smallholder farmers, influencing their access to food.

Table 3 Households climate change experiences

Climate change knowledge		Frequency	Percentage (%)
Heard of climate change	Yes	96	82.1
	No	21	17.9
Source of information	Government	1	0.9
	Friend	4	3.4
	Radio	37	31.6
	Television	46	39.3
	Newspaper	6	5.1
	School	1	0.9
	Agricultural community	1	0.9
	Don't remember	21	17.9
Reason for climate change	Low rainfall	43	36.7
	Shifted rainy season	12	10.6
	Floods	8	6.8
	Increased temperature	6	5.1
	Drought	36	30.8
	other	12	10.3
Received training on climate change	Yes	12	10.3
	No	105	89.7
Training institution	Government	10	8.5
	NGO	2	1.7
	Did not receive	105	89.7
Background of information	Awareness	12	10.3
	Vulnerability	1	0.9
	Ways of mitigation and adaptation	2	1.7
	Don't know	104	88.9
Aware of Indigenous knowledge of focusing weather	Yes	24	20.5
	No	93	79.5
Suffered effects of climate change	Yes	56	47.9
	No	49	41.9
	Not sure	12	10.3
Experienced climate shocks	Yes	93	79.5
	No	18	15.3
	Not sure	6	5.1
Lower maize yield due to low rainfall	Yes	51	43.5
	No	60	51.3
	Not sure	6	5.1
Crop diseases due to drought	Yes	32	27.4

(continued)

Table 3 (continued)

Climate change knowledge		Frequency	Percentage (%)
	No	78	66.7
	Not sure	7	5.9
Livestock diseases due to drought	Yes	29	24.8
	No	82	70.1
	Not sure	6	5.1

Source Authors work

4.4 Coping Strategies

The results indicate that 75.2% of the respondents eat food and they prefer not to cope with food unavailability. Roughly, 55.6% eat limited food to save the available food for later consumption. Approximately 51.2% indicated that they borrow food from neighbours to supplement their own available food. The minority, 17.1%, indicated that they send their family members to eat somewhere else and 15.4% of the respondents indicated that they receive food aid. Similar observations were made in Weldearegay and Tedla (2018), indicating that most households ate less food to cope with food unavailability. Other studies include Dil Farzana et al. (2017) who claimed that eating less food was common in rural communities in sub-Saharan. Some studies indicated that borrowing money to buy food was common (Shariff and Khor 2008). The results are in line with the hypothesis as most households don't have direct coping strategies that would assist with food availability amid climate change.

4.5 Determinants of Food Availability at the Household Level in Rural Communities

Table 4 shows that the Psedue-Nagelkerke R^2 was 0.337, indicating that the model explained some of the model variations. Therefore, the model explains about 33.7% of the variables (Table 5).

From the 13 measured variables, seven were significant in determining food availability for households in the community. The hypothesised variables include self-employment, receiving food aid, facing livestock diseases, distance to the water sources, information about climate change, the male role in cooking, and level of education.

Self-employment was found significant at 10% ($p = 0.1$) and positively connected with household food availability with a beta coefficient (β) = 5.762 and a standard

Table 4 Determinates of food availability: binary logit results

Variables	Estimates	Std. error	Sig
Source of gardening water	1.426	0.464	0.275
Self employed	5.762	5.710	0.077*
Receiving farm income	7.083	8.036	0.084*
Working as a domestic worker	4.800	5.480	0.169
Faced livestock diseases	−0.044	0.061	0.025**
Received food aid	2.616	2.491	0.312
Sold livestock	2.113	1.733	0.362
Distance to the sources of water	−0.568	0.139	0.022**
Knowledge of climate change	6.537	7.260	0.091*
Rise in food prices	2.092	1.544	0.317
Male head responsible for cooking	0.192	0.178	0.075*
Female head responsible for cooking	0.724	0.652	0.720
Level of education	1.622	0.441	0.075*
Cons_	0.061	0.136	0.210
Nagelkerke $R^2 = 0.337$			

Note ** and * show the level of significance at 5 and 10% levels, respectively
Source Authors work

Table 5 Respondents' coping strategies

Climate change coping strategy	Frequency	Percentage (%)
Eating non-preferred food	88	75.2
Eating limited food than preferred	65	55.6
Borrow food	60	51.2
Eating few meals	68	58.1
Buy of credit	61	52.1
Gather wild foods	34	29.1
Consume seed stock	47	40.2
Send members to eat elsewhere	20	17.1
Send members to beg	21	17.9
Aid	18	15.4

Source Authors work

error of = 5.710. The results indicate that food availability increases with having self-employment. Similar results in the study area indicated that self-employed households usually have a high level of food available and are food secure (Dodd and Nyabvudzi 2014). When households are self-employed, they have the flexibility and time to grow their food and supplement the purchased food.

Receiving aid was found significant at 10% ($p = 0.1$) and positively connected with household food availability with a beta coefficient (β) = 7.083 and a standard error of = 8.036. The results indicate that receiving aid is associated with improved food availability while keeping other predictor variables constant. Similar results indicate that households receiving food aid have more food available (Madziakapita 2008). This might be explained by the fact that households receiving food aids can supplement their food with the received food items.

Livestock diseases was significant at 5% ($p = 0.05$) and negatively connected with households' food availability with a beta coefficient (β) = −0.044 and a standard error of = 0.061. The results indicate that if there are livestock diseases the household has high chances of having less food available. Livestock diseases negatively impact food availability since households in rural communities of developing countries rely on livestock for their food (Mekonnen et al. 2021). Livestock diseases result in increased mortality, which will negatively affect food availability.

Distance to the water source was found significant at 5% ($p = 0.05$) and negatively connected with households' food availability with a beta coefficient (β) = −5.668 and a standard error of = 0.139. The results indicate that increase in distance to water sources reduces food availability. According to Dotse (2016), in rural communities, households have to fetch water from inconvenient water sources to maintain their lives and improve food availability. The distance will have an inverse relationship with the amount of water that reaches the gardens/fields. This will negatively affect food production, and food availability.

Knowledge of climate change was found significant at 10% ($p = 0.1$) and positively connected with households' food availability with a beta coefficient (β) = 6.537 and a standard error of = 7.260. The results indicate that having knowledge about climate change will increase the chances of the household having food available. Similar results were visible in Zhou et al. (2016), who claimed that households in rural areas lack access to information about climate change. Hence, the need to develop knowledge, vocational skills, attitudes, and values will foster income generation and help households increase their food availability.

Male head responsible for cooking was found significant at 10% ($p = 0.1$) and positively connected with households' food availability with a beta coefficient (β) = 0.192 and a standard error of = 0.178. The results indicate that if males are responsible for cooking there is a higher chance of having food available. This might be explained by the fact that males do not normally cook and are usually not at home, making food more available when they are responsible for cooking compared to females. According to Neuman et al. (2017), males do not usually cook since cooking is regarded as women's duty. Males usually cook for leisure or for responsibility, such as friends and family visits (Neuman et al. 2017). When males are involved in cooking, they will have knowledge of what the household needs and thus improve its availability of food.

The level of education was found significant at 10% ($p = 0.1$) and positively connected with households' food availability with a beta coefficient (β) = 1.622 and a standard error of = 0.441. The results indicate that increase in the household head level of education will increase the chances of the household having food available. Corresponding findings were observed in Ngema et al. (2018), who found that households with a high level of education have higher food availability chances than households with a low level of education. This could be explained by income availability since households with a high level of education are associated with higher incomes than households with low or no education.

5 Conclusions

The study determined the impact of climate change on household food availability. The chapter concludes that the majority of households had high food availability, indicating that food availability is not a significant problem, but access could be an issue if no action is taken. In terms of household perceptions, the majority had heard about climate change; however, the majority had never received training on climate change to adapt to shocks caused by a change in rainfall and temperature. The majority of the households were not even aware of indigenous knowledge of forecasting climate change. The chapter further concludes that factors such as being self-employed, receiving food aid, livestock diseases, distance to water sources, knowledge about climate change, male head responsible for cooking, and level of education determine food availability. The results support the hypothesis as most households in the study area are not directly coping with climate change but food availability. On the other hand, socio-economic and institutional factors drive food availability for rural communities. The socio-economic factors should be considered if sustainability in food security at the household level is to be achieved. There should also be a promotion of entrepreneurship and self-employment if food availability is to be achieved within Raymond Mhlaba Local Municipality.

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The Interconnectedness of Food Availability, Utilisation and Access from Sustainable Home-Gardens in Raymond Mhlaba Local Municipality, South Africa

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1 Introduction

Food security is established when "all people, at all times have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2006). According to Mbow et al. (2019), despite the fact that food supplies have been increasing globally since 1961, there still exists 821 million undernourished people who do not have access to food. Furthermore, 151 million children under the age of 5 years are stunted, 613 million females aged between 15 and 49 suffer from iron deficiency and more than 2 billion adults are overweight or obese. It is also estimated that more than 2 billion people experience micronutrient deficiencies, with a third of the people in developing countries being food insecure (Perez-Escamilla 2017).

There are 4 dimensions to food security. These include the physical availability of food, access to food (economic and physical), utilisation of food through the ability of the body to process and utilise nutrients through dietary quality, and stability in availability, access and utilisation of food (FAO 2006). Prosekov and Ivanova (2018) identify that the main causes of food insecurity relate to poverty, population growth, armed conflict and natural disasters. These have compromised the 4 dimensions of food security. Other factors include suboptimal livelihoods and household management strategies, as well as poor health (Perez-Escamilla 2017).

Various interventions have been instituted in order to circumvent food insecurity. These have included employment creation, safety nets and promoting home-gardens, amongst others. South Africa has been identified as a country that is food secure at the national level and food insecure at the household level. A report by IPC (2021) estimated that 9.60 million people in South Africa were in a state of crisis

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in terms of food insecurity, whilst 2.20 million people were in a state of emergency. This was due to the COVID-19 pandemic; economic decline and unemployment; food prices; and drought. There is suppressed food availability in South Africa, especially of vegetable products. Against the recommended 400 g/day consumption of vegetables and fruits, South Africans are consuming 196 g/day (Faber et al. 2011). Musemwa et al. (2013) and Ndhleve et al. (2012) found that home-gardening was actually not a significant factor influencing food access in South Africa. Home-gardens were, however, significant in food utilisation, as they improved nutrient diversity (Faber et al. 2011; Taruvinga et al. 2013; Malahlela 2014). According to Malatsi (2019) there is average stability in food obtained from home-gardens in South Africa, allowing households to obtain half of their vegetable needs from home-gardens mainly in the summer. Modibedi (2018) concurs, indicating that food stability was not a concern for gardeners in South Africa. However, this has been a one-dimensional perspective of food security for home-gardeners, either looking at the food access, availability or utilisation lenses. There still lacks an integrated study that factors in the interrelationships between these food security pillars.

In order to meet the Sustainable Development Goals (SDGs) there is need for sustainable food production. Home-gardening has been identified as an alternative way in which household can be food secure. They are the most enduring and oldest form of cultivation, supplementing food and nutritional security and livelihoods (Galhena et al. 2013). According to Galhena et al. (2013) home-gardens can be classified as homestead, compound, farmyard, backyard, kitchen or mixed. They are a small production system supplying plants that are not affordable, obtainable or readily available through wage earnings, field cultivation or retail markets (Galhena et al. 2013). They also strengthen social ties with neighbours through vegetable sharing and conserves agricultural traditions (Mushagalusa et al. 2019). Home-gardens are characterised by being a production system that the poor can enter, located near residence, occupy a small area, production is supplementary and contains a high diversity of plants (Eyzaguirre and Linares 2010; Galhena et al. 2013). Home-gardens have advantages such as enhanced food security; diversity through increased food nutrition and availability; income and employment; risk reduction through diversification; environmental sustainability through water and nutrient recycling; as well as maintenance and increase in local biodiversity (Landon-Lane 2011; Agbontale et al. 2019).

According to Singh (2021) eco-friendly farming emphasizes gardening which creates an ecological balance and a sustainable micro-environment for plant growth. Over 1 billion people in tropical and subtropical regions are dependent on home-gardens and subsistence farming for food, providing close to 80% of local food supply (Lozada 2014).

Sustainable home-gardening includes techniques related to organic gardening, conservation agriculture and permaculture (Assefa et al. 2017; Didarali and Gambiza 2019; Singh 2021). Some of the constraints faced in home gardening have included insufficient land and water, pest and diseases, lack of storage facilities and lack of capital, amongst others (Agbontale et al. 2019). In South Africa, various studies have been undertaken that try to relate home-gardens to food utilisation (Selepe and Hendriks 2014; Faber et al. 2017; Lubeka et al. 2020), food access (Shisanya and Hendriks 2011; Ndhleve et al. 2012; Baiyegunhi and Makwangudze 2014) and food availability (Faber et al. 2011; Mkhawani et al. 2016). In Nigeria, Agbontale et al. (2019) found that home-gardens were significant in food availability and accessibility. Even though authors such as Gichunge and Kidwaro (2014) have tried to ascertain these interlinkages, the study did not focus on South Africa and they used qualitative methods. According to Faber et al. (2011) in order to strengthen food security and nutrition, there is need to align "complementarities and synergies" between food availability, access and utilisation. This is due to the fact that most food security studies have taken a "silo" perspective concerning food availability, access and utilisation. The hypothesis is that there are interlinkages between food availability, access and utilisation. Any synergies will augment food security, whilst trade-offs will suppress food security. The objective of the study was to depict the interconnectedness of food availability, access and utilisation from home-gardens in South Africa. The chapter hypothesizes that there is linkage between (a) food availability and food access; (b) food availability and food utilisation; and (c) food access and food utilisation. The current study is significant due to the lack of studies that ascertain this interrelatedness, especially from a home-garden perspective in South Africa. It also offers pathways through which synergies and complementarities in the food security dimensions are promoted, and trade-offs are minimised, to optimise food security.

2 Methodology

2.1 Study Site

The study was carried out in Mavuso village (Fig. 1), which is in Raymond Mhlaba (formerly Nkonkobe) Local Municipality. The municipality is located in Amathole District Municipality, Eastern Cape Province, South Africa.

Mavuso village is located 3.6 km away from the nearest town, which is Alice, and 6.5 km from the University of Fort Hare. According to StatsSA (2011) the population of Mavuso village in the 2011 census stood at 1 188, with a total area of 0.70 km^2. There are 334 households in Mavuso, with half the population being female. Forty-eight percent of the population in Mavuso is under 35 years old, with 96.88% being Xhosa speaking (StatsSA 2011). There is high unemployment and poverty rates in Raymond Mhlaba Local Municipality at 68 and 71%, respectively. Livestock production is the major economic activity in the area (Musemwa et al. 2018).

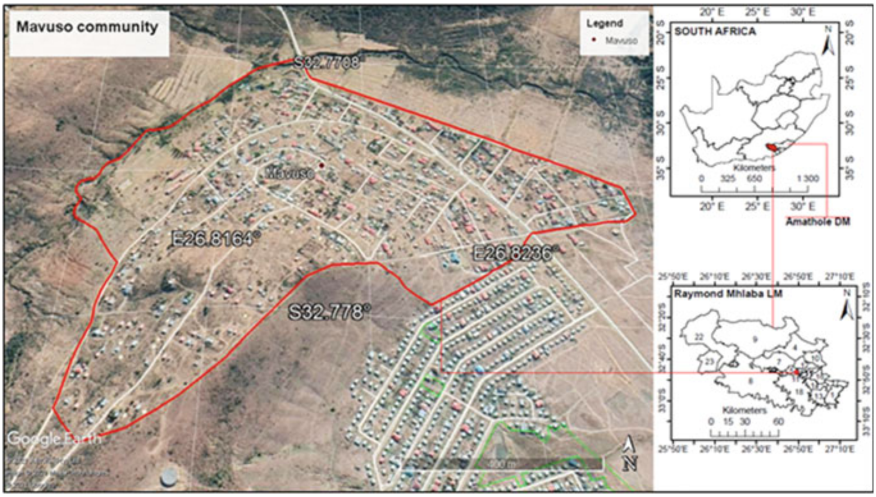

Fig. 1 Study site. *Source* Google Maps (2021)

2.2 Study Design

The study utilised a household cross-sectional survey. Simple random sampling was utilised in the study. From a total population of 334 households in Mavuso village (StatsSA 2011), Yamane (1967) method was used to calculate the sample size:

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

where n is the sample size, N is the population and e is the confidence interval. The following sample size was then obtained

$$n = \frac{334}{1 + 334(0.05)^2} \tag{2}$$

$$n = 182$$

A structured questionnaire was distributed to 182 households targeting the household head, or any other person above 18 years old. However, after data cleaning, only 116 questionnaires were eligible for further analysis.

2.3 Analytical Framework

In estimating and testing the hypotheses of the relationship between home-garden food utilisation, availability and access, Structural Equation Modelling (SEM) was utilised. SEM was utilised by authors such as Marasinghe et al. (2015). SEM allows the examination of one or more independent and dependent variables, which can either be continuous or discrete, and factors or measured (Ullman and Bentler 2003). SEM assesses interrelationships between latent and manifest variables. The following system of equations define the SEM:

$$\text{The structural equation model: } \varrho = \varrho C_{\varrho} + \xi\Gamma + \varsigma \quad (3)$$

$$\text{The measurement model for: } x\text{: } x = \varrho\Lambda_x + \delta \quad (4)$$

$$\text{The measurement model for: } y\text{: } y = \varrho\Lambda_y + \varepsilon \quad (5)$$

where ϙis "a $a \times 1$ random vector of endogenous latent variables; ξ is a $b \times 1$ random vector of exogenous latent variables; A is a $a \times a$ matrix of coefficients of the ϙvariables in the structural model; Γ is a $a \times b$ matrix of coefficients of the ξ variables in the structural model; ς is a $a \times 1$ vector of equation errors (random disturbances) in the structural model; x is a $w \times 1$ vector of predictors or exogenous variables; Λ_x is a $w \times b$ matrix of coefficients of the regression of x on ξ; δ is a $w \times 1$ vector of measurement errors in x; y is a $v \times 1$ vector of endogenous variables; Λ_y is a $v \times m$ matrix of coefficients of the regression of y on ϙ; ε is a $p \times 1$ vector of measurement errors in y." The measurement models relate the measured variables to the factors. The structural equation model relates to the relationship between the constructs (Ullman and Bentler 2003), which in the study include food access, food availability and food utilisation.

The Goodness-of-fit Index (GIF), Root Mean Square Error of Approximation (SRMR), Standardised Root Mean Square Residual (SRMR), Comparative Fit Index (CFI), (CD), Tucker-Lewis Index (TLI) and Coefficient of Determination,, were used to evaluate the fit of the SEM model. The SRMR and RMSEA should be below 0.08, whilst the CFI and TLI should be above 0.90 (Ngarava et al. 2019; Xia and Yang 2019).

3 Results

3.1 Descriptive Statistics

The food utilisation of garden products by households in the study area is shown in Table 1. In a 7-day reporting period, the households utilised cereals in 5 days, whilst

Table 1 Home-garden food utilisation of households in Raymond Mhlaba Local Municipality, South Africa

	Number of days the following food stuffs were used				
	Cereals	White tubers and roots	Vitamin A rich vegetables	Dark green leafy vegetables	Other vegetables
Mean	5.47	1.35	3.49	3.30	3.80
Std. dev	1.890	1.452	1.926	1.469	1.929
Range	7	7	7	6	7
Minimum	0	0	0	1	0
Maximum	7	7	7	7	7

Source Author

other vegetables for 4 days, and the least where white tubers and roots, for a single day.

Table 2 shows production from home-garden. In the study site, 76.7% of the households grew crops and/or vegetables. Furthermore, out of all the households that grew crops and/or vegetables, only 28.4% grew enough to sustainably provide food.

Consumption of home-garden products is shown in Fig. 2. It shows that 57.6% of the households only managed to eat their home-garden products for a few months with just 9.4% managing a full calendar year.

Households do not produce enough from the home gardens due to lack of water (43.0%), land (32.9%) and seed (21.5%), respectively (Fig. 3).

The majority of the households grew cereals (97.5%), white tubers and roots (92.2%), as well as vitamin A rich vegetables (72.2%), respectively (Fig. 4).

The cereals, white tubers and roots produced in the home-gardens included potato, maize and sugar beans, respectively (Fig. 5). The least grown were peanut, wheat and millet, respectively.

As shown from Fig. 6, beetroot was the most grown vitamin A rich vegetable in the home-gardens, followed by carrots, pumpkins, red pepper and sweet potato, respectively.

Spinach was the most grown green leafy vegetable, as depicted by Fig. 7, followed by green beans. Broccoli was the least grown green leafy vegetable in the home-gardens.

Onions, cabbages, lettuce and watermelon were the other vegetables that were grown in the home-gardens (Fig. 8).

Table 2 Production in home-garden

	Yes	No
Grow garden crops or vegetables	76.7	23.3
Produce enough to eat from garden	28.4	71.6

Source Author

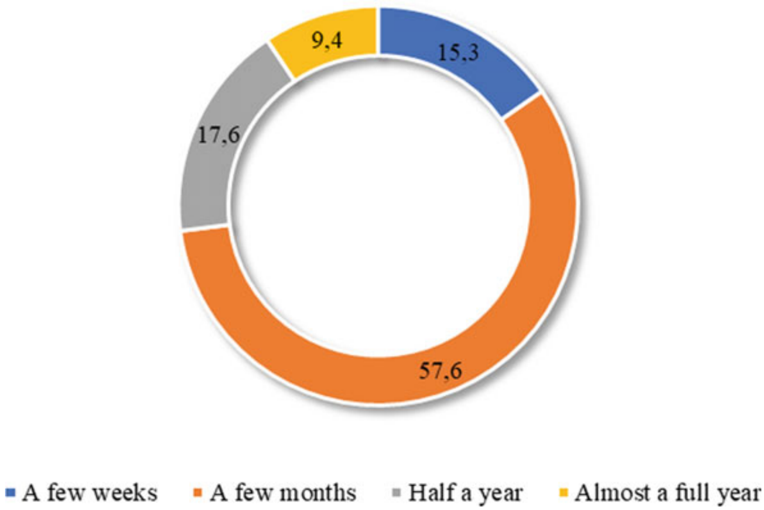

Fig. 2 How long household eats from home-garden. *Source* Author

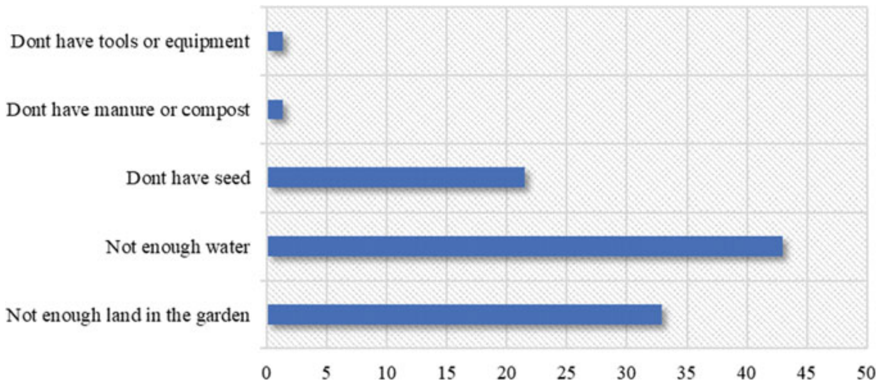

Fig. 3 Reasons for not producing enough from home-garden. *Source* Author

3.2 Empirical Results

Figure 9 shows the SEM for the relationship between home-garden food utilisation, availability and access in Raymond Mhlaba Local Municipality. The overall fit of the SEM is shown in Table 3. The CD, SRMR, CFI and Chi-square indicated an acceptable fit, whilst the RMSEA and TLI had an unacceptable fit. The model therefore was acceptable, and the estimated parameters were used in further analysis.

There was a significant positive association between food availability and the production of the home-garden vegetables (Fig. 9). Vitamin A vegetables had the

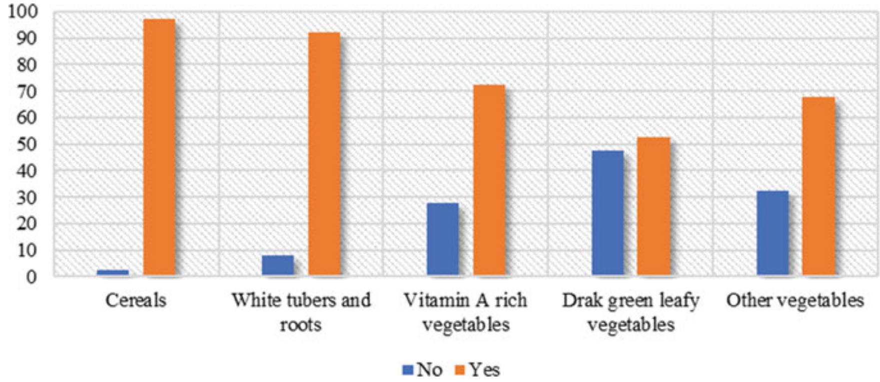

Fig. 4 Types of cops and vegetables grown in home-gardens. *Source* Author

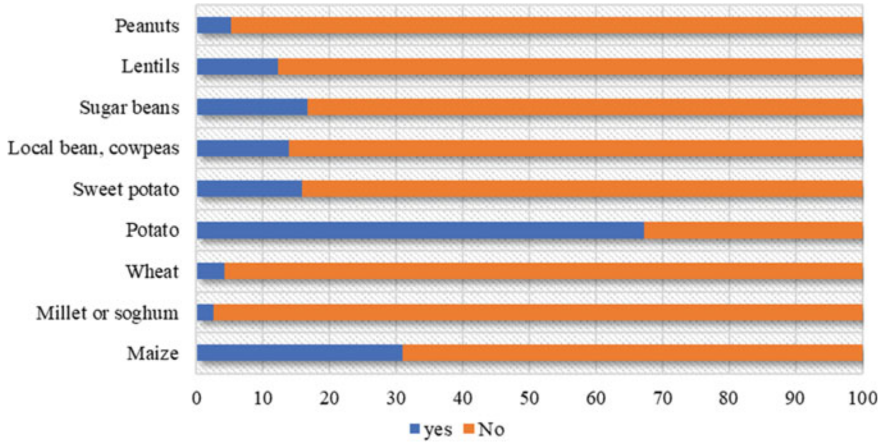

Fig. 5 Households that produce cereals, tubers and roots in their home-gardens. *Source* Author

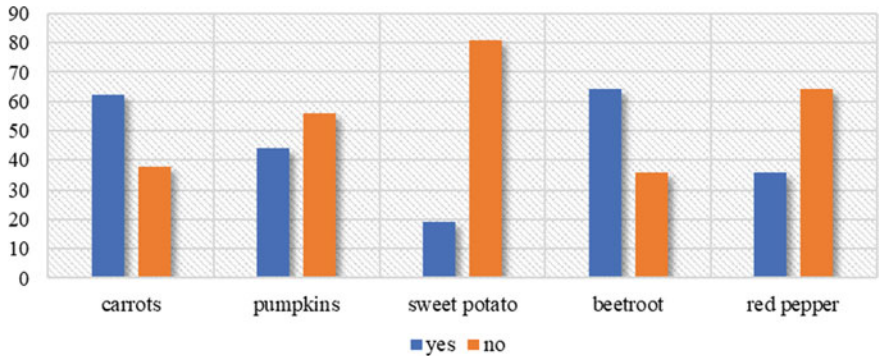

Fig. 6 Households that produce Vitamin A vegetables in their home-gardens. *Source* Author

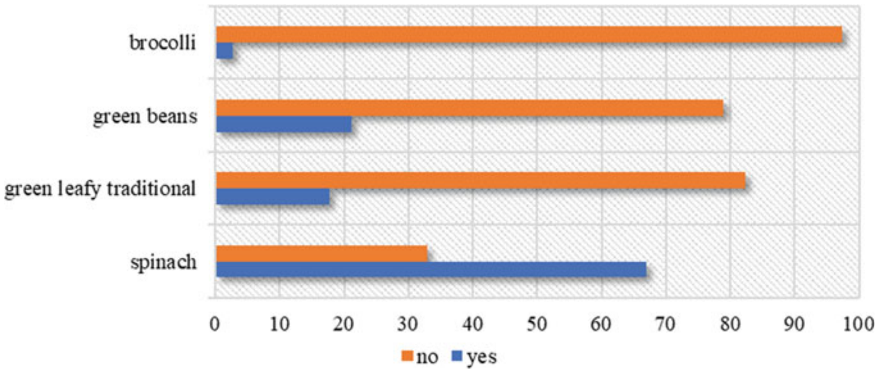

Fig. 7 Households that produce dark green leafy vegetables in their home-gardens. *Source* Author

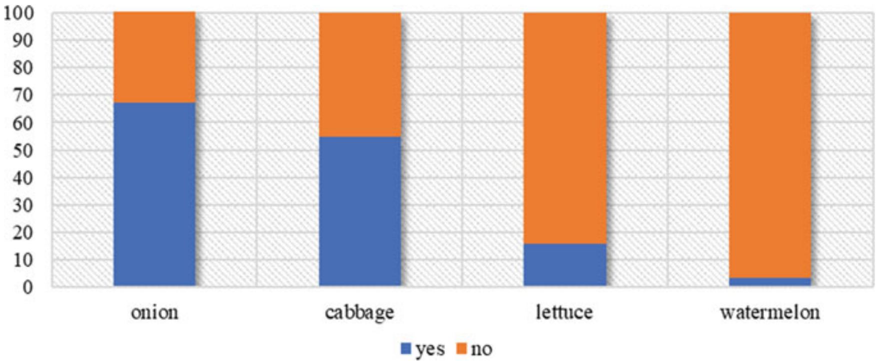

Fig. 8 Households that produce other vegetables in their home-gardens. *Source* Author

highest association with food availability, followed by other vegetables and dark green leafy vegetables, respectively.

Figure 9 also shows a significant association between food accessibility and how long the households eat out of their own production. The association was however negative, indicating less food accessibility when the household is involved more in eating from the home-gardens.

There was significant positive association between food availability through home-garden production and food accessibility from the duration with which they eat out of their own production. No association was evident between food utilisation through the number of days the home-garden produce is eaten and food accessibility and availability, respectively. The results therefore reject the null hypothesis of no association and interrelationship between food availability and food accessibility through home-gardens. The null hypothesis of no association and interrelationship between food availability and food utilisation is accepted, as there was none that was

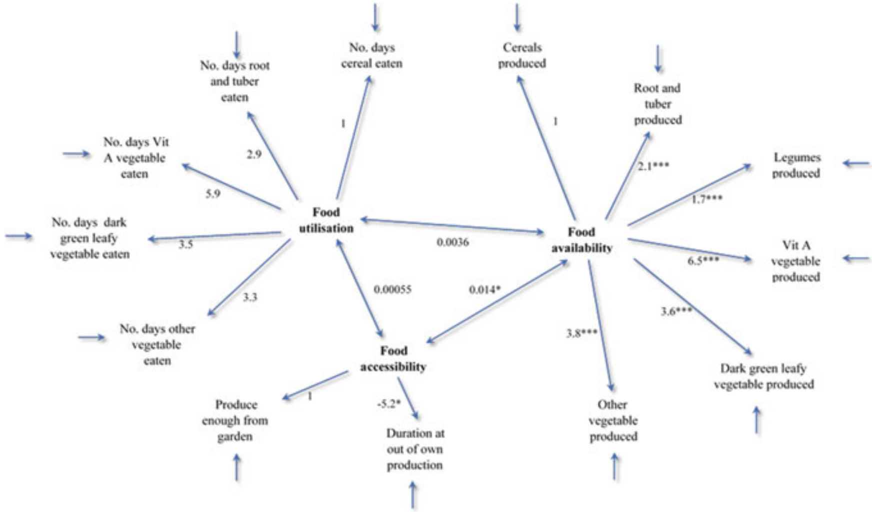

Fig. 9 SEM of food utilisation, availability and accessibility in Raymond Mhlaba Local Municipality. *Source* Author

Table 3 Model fit statistics

Fit statistic		Value	Threshold	Decision
Likelihood ratio				
	Chi-sq	450.838***		Acceptable
Population error				
	RMSEA	0.084**	< 0.08	Not acceptable
	pclose	0.048		
Information criteria				
	AIC	2712.421		
	BIC	2818.503		
Baseline comparison				
	CFI	0.904	> 0.90	Acceptable
	TLI	0.879	> 0.90	Not acceptable
Size of residual				
	SRMR	0.074	< 0.08	Acceptable
	CD	0.987		Acceptable
Sig. at **5%, ***1%				

Source Author

Table 4 Equation-level goodness of fit

Dependent variable	Fitted	R-squared	Correlation
Number of days cereal is consumed	2.61	0.03	0.17
Number of days white tuber and roots are consumed	2.34	0.28	0.53
Number of days Vitamin A vegetables are consumed	3.35	0.80	0.89
Number of days dark green leafy vegetables are consumed	1.83	0.50	0.71
Number of days other vegetables are consumed	3.27	0.25	0.50
Cereal production	0.22	0.24	0.49
White tuber and root production	0.41	0.56	0.75
Legume production	0.44	0.34	0.59
Vitamin A vegetable production	2.62	0.83	0.91
Dark green leafy vegetable production	0.94	0.70	0.83
Other vegetable production	1.11	0.66	0.81
Produce enough	0.07	0.02	0.15
How long does it sustain you	0.67	0.06	0.24
Overall		0.99	

Source Author

evident from the results. Furthermore, the null hypothesis of no association and interrelationship between food accessibility and food utilisation is also accepted as indicated through the results. The results therefore indicate a relationship between food availability and access through home-gardening. There is no relationship between food availability and utilisation, as well as between food accessibility and utilisation.

Table 4 shows the regression level variables from the SEM model. High goodness of fit is observed when Vitamin A vegetable production is the dependent variable (83%), followed by the number of days Vitamin A vegetables are consumed (80%) and dark green leafy vegetable production (70%). The least is enough production from home-garden (2%), number of days cereals are consumed (3%) and how long home-garden production sustains the household (6%). The correlations also follow this pattern. The overall fit of the model is 99%.

3.3 Home-Garden Sustainability Results

Close to half of the household utilise community taped water for their home-gardens (Fig. 10), followed by household taped water (23.4%) and rainwater harvesting (14.4%), respectively.

Figure 11 shows that 63.7% of the households obtained their home-garden water using buckets.

Sixty-seven percent of households walk less than 200 m from the nearest water source, whilst 1% walk for more than a kilometre (Fig. 12).

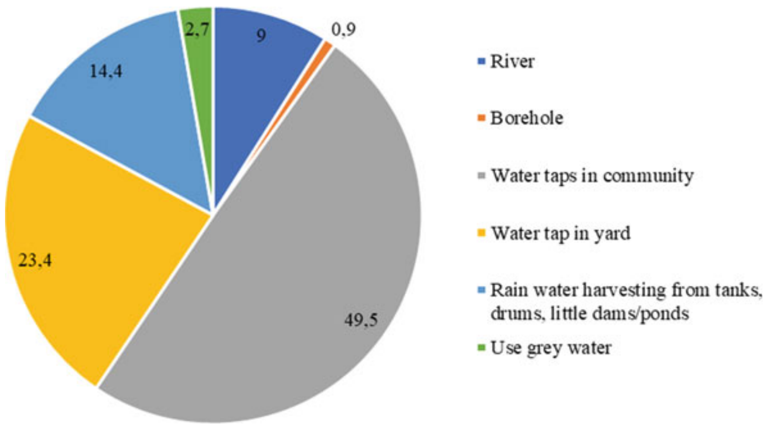

Fig. 10 Source of water for home-garden. *Source* Author

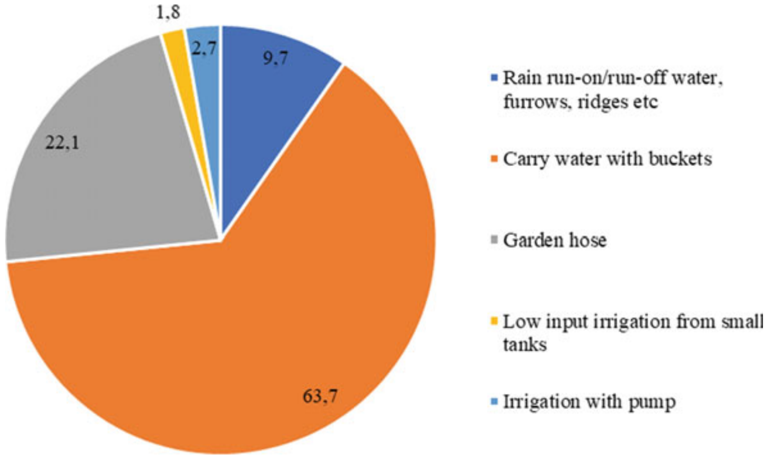

Fig. 11 Water source for home-garden. *Source* Author

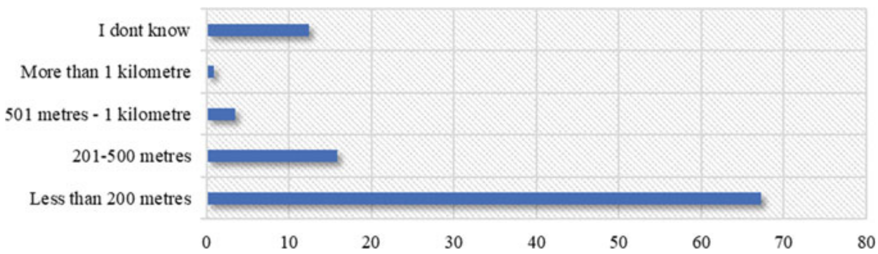

Fig. 12 Distance to water source for home-gardening. *Source* Author

Table 5 Shock experiences to home-gardening

Experiences	Yes (%)	No (%)
Suffered climate change	53.3	46.7
Experienced any shocks	83.8	16.2
Lower yields due to droughts or floods	45.9	54.1
Crop disease or pest disease	29.1	70.9
Significant fall in sale prices for crops and livestock	1.8	98.2

Source Author

Table 5 shows that 53.3% of the households have suffered the effects of climate change, with 83.8% having experienced some kind of shock. Relating to home-gardening, 45.9% have experienced lower yields through droughts or floods, 45.9% crop disease or pest disease, whist 1.8% have endured reduction of sale price for agricultural produce.

4 Discussion

Households in the study area were mostly utilising cereals, Vitamin A rich vegetables and dark leafy green vegetables, respectively. Faber et al. (2017) highlighted that there were significant differences in consumption of home-garden products. A study by Selepe and Hendriks (2014) found that participating in home gardens had significant influence on consumption of cereals, vegetables as well as seeds, nuts and legumes. This was augmented by Lubeka et al. (2020).

The majority of the households grew crops and vegetables but however did not grow enough to eat from the home-gardens. In the majority of the households, the home-gardens could only sustain them for a few months. In contrast, Adekunle et al. (2013) found that in Nkonkobe (now Raymond Mhlaba), Eastern Cape Province, households were dependent on their own production. Lack of water was a major reason why household did not produce enough from home-gardens, followed by lack of land and seed, respectively. Wills et al. (2009) also found that access to water and land were major constraints in gardens. The study was however in the urban areas of Johannesburg, South Africa, where there is extreme pressure on urban spaces. The findings can also be applicable in the Raymond Mhlaba Local Municipality because of the shortage of water infrastructure to utilise in their home-gardens.

Majority of household grow cereals, roots and tubers as well as vitamin A rich vegetables, respectively. Potatoes, maize and sugar beans were mostly grown whereas peanuts, wheat and millet were the least grown for cereals, white tubers and roots, respectively. Beetroot, pumpkin, red pepper and sweet potato were the most grown vitamin A rich vegetables, respectively. For dark green leafy vegetables, spinach was extensively grown, followed by green beans, while broccoli was the least grown. Other vegetables that were grown include onion, cabbages, lettuce and watermelons, respectively. A study by Faber et al. (2017) highlighted that food secure household had significantly more frequent intake of tomatoes, lettuce, green beans, cauliflower, broccoli and beetroot. Furthermore, the food secure households had less intake of sweet and white potato, pumpkin and cabbages. Taruvinga et al. (2013) found that most of the households in Amathole District Municipality consumed potatoes, grains and beans, respectively. Adekunle et al. (2013) found that in Nkonkobe (now Raymond Mhaba), Eastern Cape Province, spinach was the most produced vegetable in home-gardens, followed by potatoes, cabbages, onion and tomato, respectively. Thus, depending on a particular location, social and cultural norms, there will be various combination of food that are grown and eaten from the home-gardens.

There was significant positive association between food availability and food accessibility through home-gardening. There was no association between food utilisation and food accessibility, as well as between food utilisation and availability. Cheteni et al. (2020) found that dietary diversity was not a major concern for households in a study in South Africa. This can explain why there was no association between food utilisation and food availability and access. There was also significant positive association between food availability and the production of home-garden vegetables. Food availability was mainly enhanced through vitamin A vegetables, followed by other vegetables and green leafy vegetables, respectively. There was also significant negative association between food accessibility and the duration with which their home-garden products sustain them. This is due to the fact that as more home-garden products are consumed, the less that will be accessible. According to Agbontale et al. (2019) home gardens have significant influence on food availability and access. The study was however devoid of establishing any association between food availability and food access.

According to Ibnouf (2009) women who are responsible for home-gardening and have access to food production sources improve dietary diversity and household food security. The findings of the study contradict Akrofi et al. (2010) as well as Selepe and Hendriks (2014) who found that home-gardens had significant impact on dietary diversity through food utilisation. In the current study, food utilisation had no association with the other aspects of food security. Agbontale et al. (2019) found that home gardens were significant in food availability and food access. The study did not however go further to establish association between food availability and food access. Musemwa et al. (2013) and Ndhleve et al. (2012) found that home-gardens had no significant impact on access to food. Ndhleve et al. (2012) attributes this to the size of the gardens that are inadequate to generate enough food. Baiyegunhi and Makwangudze (2014) did however find that home-gardens were significant in improving food access.

Ruysenaar (2013) acknowledges that food availability considers how much was produced and when it was available. Furthermore, home-gardens improved food availability and access, at varied scales depending on the food type. In a study by Gichunge and Kidwaro (2014), interrelationships between food availability, access and utilisation were established. The study was however qualitative and not inferential. Traditional foods were made available and accessible at little to no cost ensuring healthy food choices. According to Thornton (2008) food access from home-gardens is compromised by the relatively small land holdings, thereby compromising production. Mkhawani et al. (2016) found establishment of home-gardens being necessitated by the unavailability of food. Al-Mamun et al. (2010) aver that home-gardening was necessitated because of seasonal unavailability of certain foods. It provides direct access to important nutrients which may not be readily available.

Most of the households utilise community taped water for their garden, followed by home taped water and rainwater harvesting, respectively. They utilised buckets in watering their home gardens. The water sources for their home-gardens were located within a walking distance of 200 m. Trefry et al. (2014) also highlighted that watering distances from communal taps were 200 m within the Eastern Cape. Furthermore, the households were utilising watering cans to water their gardens. Adeosun et al. (2020) and de Klerk et al. (2004) found inaccessibility of water constraining home-gardens, with piped water offering a solution. However, the sustainability of such initiative is questionable given the opportunity cost of water in terms of drinking and sanitation. Legesse et al. (2016) highlighted that distance to water source had a significant negative impact on returns obtained from home-gardens. The further the distance, the less the returns (Legesse et al. 2016). Pests and diseases as well as unreliable water were constraints to home-gardens that were identified by Agbontale et al. (2019). Rainwater harvesting has been identified as a sustainable alternative in alleviating water constraints for home gardening (de Klerk et al. 2004).

Over half of the households had experienced climate change and shocks, with close to half experiencing lower yield through droughts or floods, and a third having experienced crop disease or pest disease. However, there was little fall in sale prices for agricultural products. Adeosun et al. (2020) found poor access to climate change information, low agricultural commodity prices, pests and disease affecting home-gardens. In South Africa, Faber et al. (2017) found that there was food security differences in households that experienced plant pest and disease. D'Haese et al. (2013) added on, identifying that drought was a significant constraint. Climate change and extreme water challenges were also identified by Drimie et al. (2009) as major constraints to agricultural related activities.

5 Conclusion

Food security perspectives for home-gardeners has taken a silo approach, either focussing on food access, availability or utilisation. An integrated approach was utilised by the study in order to show the relationships between these pillars of food security. The study found that there were variations in the food that is grown in the home-gardens. Furthermore, there was positive association between food availability and food access. In this instance, the hypothesis of a relationship between food availability and food access was confirmed. However, there was no association that was found between food availability and food utilisation, as well as between food accessibility and food utilisation. Thus, the hypotheses of a relationship between food availability and utilisation, as well as between food access and utilisation were rejected.

Positive association was also observed between food availability and production of Vitamin A vegetables. Negative association was, however, observed between food accessibility and the duration with which the home-gardens sustain the households. In conclusion, there was a relationship between food availability and food access, with less emphasis on food utilisation. Dietary diversity was not a major concern for households that practiced home-gardening. Promotion of food utilisation from home-gardens is required to improve dietary diversity and food security, through countering trade-offs with food availability and food access. In order to improve food availability from home-gardens, there is need to improve production through provision of infrastructure relating to water supply. Enhancing access to suitable land can also aid in improving food access and utilisation for the home-gardeners.

6 Limitation and Areas of Further Study

The study assessed the interconnectedness of the pillars of food security utilising home-garden produced food. However, households do not entirely rely on home gardens for their food security. This offers a limitation and a pathway to new insights for food security in households that practice home-gardening. Furthermore, the other pillar of food security, which is sustainability in the food availability, access and utilisation, was not considered in the study. This is an avenue worth pursuing in order to augment the current study.

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Food Security in a Floodplain Country—Case of Bangladesh

Ahmed Ishtiaque Amin Chowdhury, Sonia Binte Murshed, and Mohammad Rezaur Rahman

1 Introduction

Being a floodplain country, Bangladesh is mostly covered by productive land. Historically, the Bengal Subah, which includes the now-Bangladesh and West Bengal, had the largest regional economy (Roy 2010). The fertile soil produced enough food to support other parts of India as such the Bengal was called the granary of the east (Stewart 1910). It had been claimed that the price of rice was one rupee for 8 maunds or 640 pounds at the time of Mughal subahdar Shaista Khan (Allen 1912; Banglapedia 2012b). In the eighteenth century, the price of grain was about one-third in Bengal, compared to Britain, in terms of silver coinage (Parthasarathi 2011). In the 1960s and early '70s, Bangladesh was widely known for natural disasters, such as floods, cyclones, drought, etc. that frequently caused damage to crops, resulting in food shortages, and also sporadically, famine. It was around this period that the country was also referred to as a "Basket case". The country has come a long way since then. In more recent years of this early twenty-first century, Bangladesh is now the 4th largest rice producer in the world for the last consecutive five years (2015–2019) (FAOSTAT 2021).

Despite the high density of population and low availability of per capita cultivable land, the country has still been able to achieve high production of many crops, including rice and fish, two staple foods for a common Bengali. It is the country's productive floodplain that has made it possible. The per capita income of the country

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is increasing rapidly in recent times, with concurrent changes in food habits that may require a shift to a new food production regime. Whether this productive floodplain can sustain a higher production regime, with a variety of new food groups, is a question and concern. Based on current observations, we want to argue that it is possible and it will be a no-regret approach, if we take a Nature-based Solution (NbS) approach. Secondary data from recognized sources and literature are utilized in the current study to establish this hypothesis. Current projections show that we shall be able to fulfill the need in the next 20 years. This paper suggests adopting this change while we are "ahead of the curve", i.e., while we are already producing enough to ensure sustainable food production to meet the future demand.

A brief description of the floodplain, its current production, the growth potential, and a general discussion on sustainability are provided in the subsequent sections.

2 Floodplain Context

Bangladesh, located in the South Asia, is known for its flat topography gently sloping from the north towards the south into the Bay of Bengal with approx. half of the country lying below 10 m above mean sea level (msl). According to Banglapedia (2012a), the country is crisscrossed by about 700 rivers, their tributaries and distributaries, including 57 transboundary rivers entering Bangladesh from India and Myanmar. Of these, Ganges, Brahmaputra and Meghna are the largest rivers of the country, forming one of the largest deltaic systems of the world (Fig. 1). In fact, the floodplains of the Ganges, Brahmaputra, Meghna and other smaller rivers constitute 80% of the country (Brammer 1990).

A floodplain can be defined as a "*low-lying land adjacent to a river and subject to periodic inundation from overflow from the river and other sources*" (Opperman et al. 2013). Floodplains are often acquired for the construction of urban settlements, embankments, industries and industrial zones, roads and other infrastructures. Following the devastating floods of 1954 and 1955, then East Pakistan (now Bangladesh) government initiated 58 Flood Control, Drainage (and Irrigation) (FCD/I) projects, which included construction of embankments, sluice gates and irrigation facilities to protect the crops from floods and ensure food security (Chowdhury et al. 1996; Wester and Bron 1998). In the last 60 years (1959–2019), 4 barrages, 16,261 km of embankments (including 139 polders), 15,355 water control structures, and 1401 closures have been constructed in Bangladesh (BWDB 2020). FCD/I project areas cover approx. 55% (6.46 million hectares (mha) compared to 11.8 mha) of the country's land area, excluding the area of rivers and forests (BWDB 2020).

Improper or unplanned construction of water resources structures such as regulators, and in some cases embankments, causes loss of floodplain connectivity with the rivers. Floodplains constitute more than 50% of the agro-ecological zones of Bangladesh, thus, playing a vital role in agriculture. It is recognized that water pollution, siltation, FCD/I projects, channelization of rivers, unplanned construction of

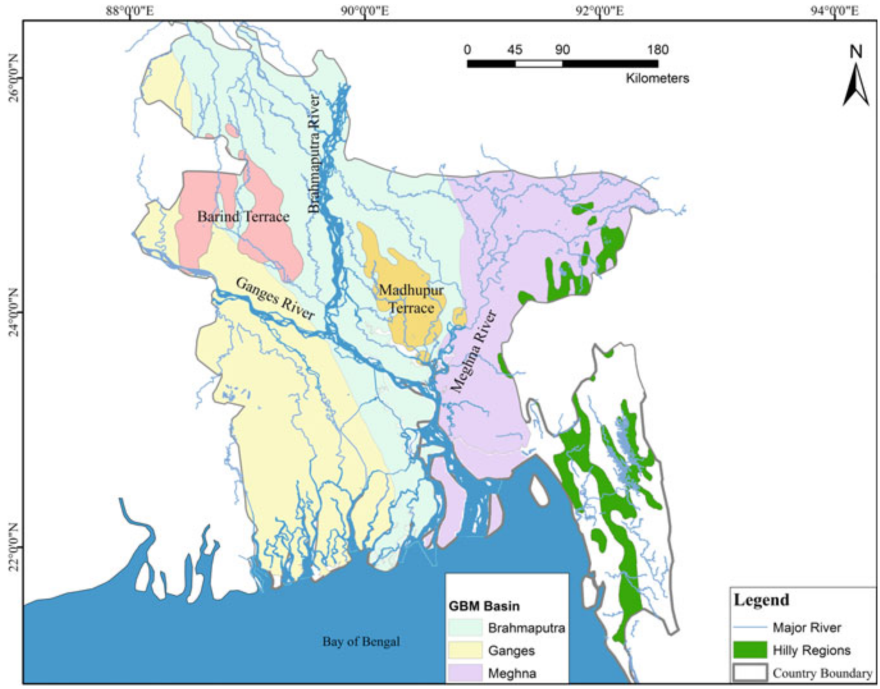

Fig. 1 Floodplains of Bangladesh

roads, dams and embankments, etc. are the major causes of the decline in inland capture fish in Bangladesh (BDP-2100 2018; NEMAP 1995). The FAP-17 (1995) study assessed the impacts of FCD/I projects on floodplain and reported that such interventions cause loss of habitat, reduction in catch per unit area, lower fish abundance, decreased biodiversity, reduction in migratory fish and reduced fish migrations, etc. Waterlogging, from excessive rainfall and/or flood, inside the embankments and coastal polders are reported to cause inundation of agricultural lands leading to damages to crops (Alam et al. 2017; Noor 2018). Over extraction of groundwater, due to the unavailability of surface water sources, increased salinity in rivers, and lower rate of groundwater recharge, have resulted in falling groundwater table in different regions of the country. Surface water sources cover only approx. 21% of the irrigated area while the rest 79% is covered by groundwater sources. In the northwest region 95% of irrigation water is sourced from the aquifer, and thus, causes a lowering of the groundwater table (GED 2020b; Mojid et al. 2019). The situation particularly worsens in the dry season, putting further stress on groundwater to meet the required irrigation water for the winter variety of rice cultivation. For example, the winter variety (i.e., Boro rice) is cultivated in the dry season (November to May–June) in all levels of floodplain and requires intensive irrigation. Monsoon in Bangladesh extends from May to October when rainfed and monsoon rice varieties (i.e., the Aus and Aman rice, respectively) are cultivated.

3 Production in Floodplain Regime

Bangladesh has made notable progress in rice production since it's independence in 1971, especially over the last two decades. The total rice production has increased from approx. 10.1 mt in 1972 to approx. 36.4 mt in 2019, a more than 260% increase during this period (Fig. 2). However, the total harvested area has increased a little (9.63 million ha (mha) in 1972 to 11.52 mha in 2019, a 19.6% increase) over this same period. This translates to a threefold increase in the yield of the area harvested. The increased production helped Bangladesh to achieve self-sufficiency in rice production and thus, ensure food security (GED 2020b). The country has also succeeded in increasing production of non-rice crops, such as potato, wheat, maize, oilseeds, pulses, vegetables, and fruits. Potato, in this regard, is chosen as an example of non-rice crop, which is considered as one of the major crops in Bangladesh. In 1961, the area under potato cultivation was 0.056 mha which increased to 0.076 mha and 0.13 mha in 1972 and 1998, respectively. The corresponding potato productions were 0.34 mt (1961), 0.75 mt (1972) and 1.55 mt (1998), respectively (Fig. 2). In the subsequent year, 1999, the area for potato cultivation nearly doubled to 0.24 mha and further to 0.47 mha in 2019 with a production of 2.76 mt and 9.66 mt in 1999 and 2019, respectively. The potato production in the last two decades exceeded the local demand, leading to estimated export of as little as 270 tonnes (1999) to 136,469 tonnes in 2014 (FAOSTAT 2021). The yield data is also shown in Fig. 2 for interested readers.

According to the Department of Agriculture Extension (DAE) (2016), 60 or more types of vegetables are produced in 2.63% of cultivable lands of Bangladesh. Most of the vegetables are grown during winter i.e., the robi season. Historical production of primary vegetables gradually increased from 0.94 mt in 1972 to 1.74 mt in

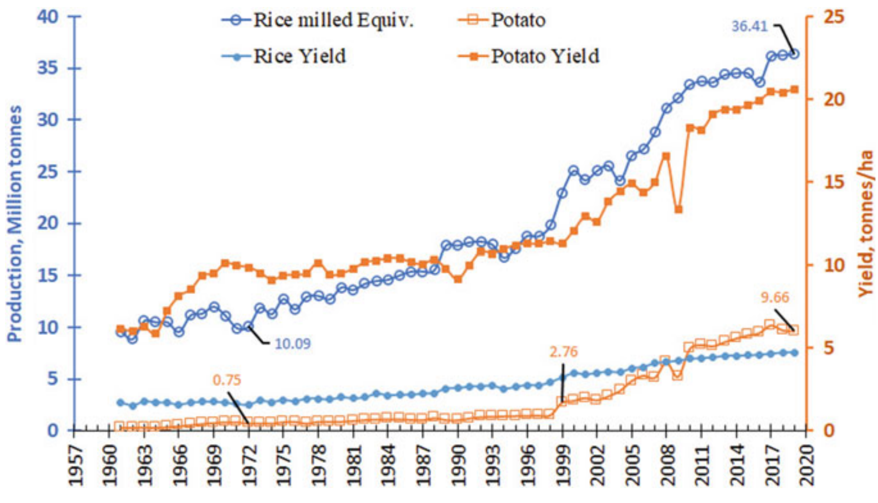

Fig. 2 Historical rice and potato production and yield in Bangladesh *Source* FAOSTAT (2021)

2003. The cropland utilized for vegetables doubled during this period, increasing from 0.15 mha to 0.30 mha. The cropland area utilized as well as the production of primary vegetables then increased in the subsequent years, with a boost of vegetable production from 2.01 mt to 6.30 mt in 2004 and 2019, respectively. It is reported that, globally, Bangladesh has the 3rd highest growth rate in vegetable production in 2018 (UNB 2018).

The fisheries sector has been one of the most productive sectors in Bangladesh for the last two decades. This sector contributes 3.5% to the national GDP and shares one-fourth of the total agricultural GDP of the country (GED 2020b). According to The State of World Fisheries and Aquaculture 2020, Bangladesh is the 3rd highest producer of inland capture fishes with 1.22 mt of live fishes, and 5th highest aquaculture fish producer with 2.4 mt fish captured in 2018 (FAO 2020). The amount of inland capture and aquaculture fishes in Bangladesh accounts for 10% and 2.93%, respectively, of global production. The total fish production in Bangladesh has gradually increased from 0.086 mt in 1989–90 to 4.4 mt in 2019 (GED 2020b). Since the mid-80s and early 90s, aquaculture started growing in Bangladesh. In recent years, it is estimated that inland open water, aquaculture, and marine capture shares are 28.19%, 56.76%, and 15.05%, respectively, in 2018–19 (DoF 2019). Sustained fish production has rendered Bangladesh self-sufficient in fish production.

The livestock sector in Bangladesh is a promising field contributing approx. 1.7% of the country's GDP (WB 2018). Cattle farming is the least developed share in this sector, that is mostly dominated by household farming and smaller agro-farms. In contrast, poultry is the most commercially developed part of this sector. Over the last four decades, the number of cattle heads increased from 21.6 million heads (mhd) to 24.2 mhd (FAOSTAT 2021). The number of goats had remarkable growth over this period, increasing from 9.21 mhd in 1980 to 61.11 mhd in 2019. Bangladesh is now the 6th highest producer of goats in the world (FAOSTAT 2021). Similar growth is observed for ducks which increased from 15.56 mhd in 1980 to 57.11 mhd in 2019. For Bangladesh, the most prominent growth has been seen in the share of chicken heads, which increased from 52.1 mhd in 1980 to 286.9 mhd in 2019

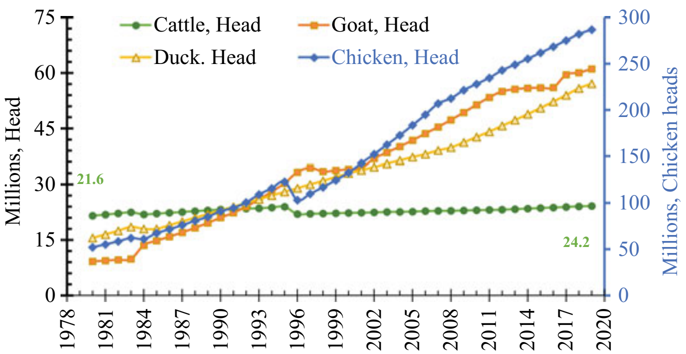

Fig. 3 Historical data of cattle, goats, chicken, and duck in Bangladesh. *Source* FAOSTAT (2021)

(FAOSTAT 2021). The growth in the livestock sector resulted in increased per capita protein intake. Considering 3-yearly average data, the consumption of animal protein has nearly doubled over the last two decades with consumption increasing from 6.3 g per capita per day in 2000–02 to 11 g per capita per day in 2015–2017 (FAOSTAT 2021).

4 Future Production Regimes

Despite the continued increase in agricultural (crops, livestock, fisheries, poultry) production for the last few years, it remains an open question whether this growth or supply can be sustained to meet the demand of the next decades.

The per capita Gross National Income (GNI, at current US$) has been slowly increasing during 1996–2016. The Perspective Plan 2021–2041 projects a further increase in GNI from $2250 in 2021 to close to $6000 in 2031, and more than $17,000 in 2041 despite the increase in population (Fig. 4). With the continued growth in income, it is projected that the changes in food diversification would continue as well. Secondary data shows that the national average per capita rice consumption decreased from 464.3 g in 1996 to 367.2 g in 2016 with increased consumption of vegetables (152.5–167.3 g), egg (13.9–15.6 g), and fish (57.5–62.6 g) over the same period, as shown in Fig. 4, suggesting increased diversification in food consumption (BBS 2018; GED 2020b; HIES 2005, 2010, 2016). The total calorie consumption from cereal crops has decreased from 92% to 89% between 1990 and 2010. It is projected that, with the increase in GNI, the share of calorie consumption from cereal would further reduce to 87% by 2031 and to 86% by 2050 (GED 2020b). The calorie intake from non-cereal crops e.g., potato, vegetables, animal and fish protein, is expected to increase.

Year	grams per capita			
	Rice	Vegetables	Egg	Fish
1996	464.3	152.5	13.9	57.5
2000	458.5	140.5	15.8	58.0
2005	439.6	157.0	14.2	42.1
2010	416.0	166.1	14.3	49.5
2016	367.2	167.3	15.6	62.6

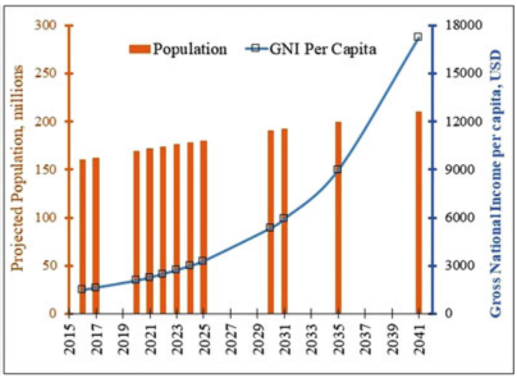

Fig. 4 Changes in food consumption, population and per capita gross national income (BBS 2018; GED 2020b; HIES 2005, 2010, 2016); dark to light shade indicates values in decreasing order

DAE projected that the production of rice, wheat, potato, oilseeds, vegetables, maize, spices and pulses will keep increasing for the next five years until 2025. The Perspective Plan of Bangladesh 2021–2041 has further projected the demand and supply of these produce for 2031 and 2041. It is estimated that Bangladesh would have surplus rice, potato, meat, milk, and freshwater fish in both 2031 and 2041. In contrast, the country may suffer from a shortfall of wheat, maize, pulses, and vegetables according to the same projection.

Although fish production seems promising, the future predictions show a downward trend in the fisheries sector. The next ten years' projection by BDP-2100 estimates that despite the growth of culture fishes, the share of inland capture fisheries would continue declining at 0.5% due to underinvestment in floodplain fisheries (BDP-2100 2018). It is noteworthy here that a total of 260 indigenous freshwater fish and 24 prawn species have been recorded in Bangladesh which is reported to be more than the number of species found in all of Europe (Capistrano et al. 1994; Chowdhury et al. 1996). Many of the small indigenous fish species are reported to be endangered, or are already in critically endangered states (Craig et al. 2004; IUCN 2000; Shamsuzzaman et al. 2017).

5 Potential with Nature-Based Solution (NbS) in Floodplains

A closer review of the FAOSTAT (2021) data reveals that the production of rice, vegetables, fresh fruits, lemons and limes, onions, garlic, ginger, lentils, potatoes, fisheries, livestock and poultry etc. have increased either steadily for decades or in recent years. In the following section, the potential of these increase with nature-based solutions (NbS), if adopted within the floodplain, is discussed.

5.1 Potential of Rice Production

One of the salient factors of the increased rice production is the cultivation of high yield rice varieties on approx. 66% of rice land, which is mostly floodplain (BRKB 2021). Banerjee (2010) has shown that cultivable land in "more flood[1] (MF)" zones account for 62,018 ha compared to 54,313 ha in "low flood (LF)" zones. The utilization of more land in agriculture in the MF zones implies that the benefits of floods and floodplains are already well perceived by the farmers. The same study also showed that, in general, the yield rate of rice in a normal flood year increases compared to the historical average yield rates. The scenario is different for different varieties in

[1] A region is designated as "more" flood prone if "*50% or more of the total area is susceptible to flooding to a depth of 90 cm or more during a normal flood event*" while others are considered less flood prone (Rogers et al. 1989).

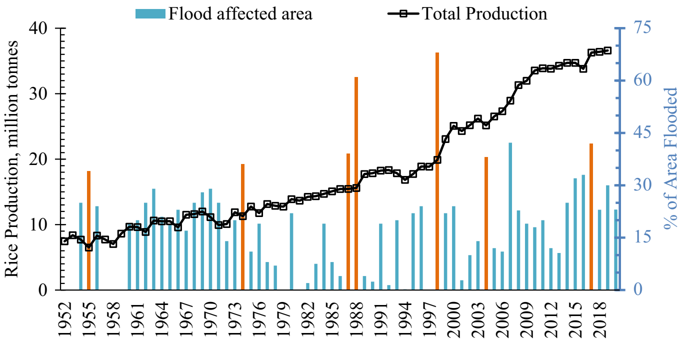

Fig. 5 Historical major floods, flooded area and rice production. *Source* Asada et al. (2005), Banerjee (2010), BBS (2011, 2020), Hofer and Messerli (2006) and various newspapers for recent data

an extreme flood[2] year. The yield of both rainfed and monsoon varieties declines in both LF and MF districts (across the country) in an extreme flood year; however, the monsoon variety is more impacted than the rainfed variety. Yields of these two varieties decrease by 1.3% and 0.9%, respectively, while that of the winter variety increases by 9% in extreme flood years compared to annual average historical yield rates (Rogers et al. 1989).

The beneficial influence of floods on rice production is further illustrated in Fig. 5. Some of the historically major floods identified were those that occurred in 1955, 1974, 1987, 1988, 1998, 2004 and 2017 (Asada et al. 2005; Banerjee 2010; BBS 2011, 2020; Hofer and Messerli 2006) and various newspapers for recent data). This figure reveals that the total rice production increased in the year following a major flood. As discussed above, severe monsoon floods cause damage to rainfed and monsoon varieties, but increased production of winter variety compensates for the loss resulting in a net increase in total rice production. The increase in winter variety results from the cultivation of "High Yield Varieties (HYV)", availability of residual floodwater for irrigation, and possibly, increased soil fertility due to the floodwater (Asada et al. 2005). The severe floods inundating the floodplains also extend the winter variety cultivation area contributing to increased production. The winter variety (local and HYV/hybrid combined) accounts for more than 50% of total rice production in recent years.

The practice of cultivating local rice varieties has gradually declined, and HYV (and hybrid) varieties have evolved as the HYV crops yield more than local varieties.

[2] The monsoon floods in Bangladesh can be generally classified as a "Normal" flood or an "Extreme" flood depending on the area, duration and depth of inundation on the adjoining floodplain. "*A normal flood is an event when approx. 20% or less of the area is inundated for continued 3 weeks or lesser duration during the monsoon. The extreme floods are the events when approx. 35% of the country is inundated for a month or more with water standing 2 m or more in most areas and 3 m or more in low-lying areas*". Examples of extreme or catastrophic floods are those of 1974, 1987, 1988, 1998, 2004, 2009 and 2017. The normal floods, in contrast, occur almost every year and people are adapted to cope with such events (Banerjee 2010).

Since the last decade, HYV varieties of rainfed, monsoon and winter varieties account for more than 90% of rice production. Both rainfed and monsoon varieties are sowed and harvested within the pre-monsoon to monsoon season, whereas the winter variety, particularly the winter-HYV, is cultivated post-monsoon and harvested before the onset of monsoon the following year. Therefore, winter-HYV is not susceptible to monsoon flooding although flash flood, particularly in the north-eastern haor region, sometimes causes damage to winter variety as well. Moreover, increased irrigation coverage has replaced rainfed and monsoon varieties that used to be grown in the flood prone areas in the rainy season, and encouraged the cultivation of winter varieties. More than 50% of the country's total rice is now being produced in the dry season, thus, saved from the damages from monsoon floods (Brammer 2016). This is one of the major factors leading to increased rice production in Bangladesh.

As discussed above, with the increasing production of crops, there is a concern of whether Bangladesh could sustain higher crop production, let alone maintaining self-sufficiency. This is because of the increasing food demand from the increased population, and the loss of agricultural land. Miah et al. (2013) reported that agricultural land had declined by about 0.26% annually from 1976–77 to 2010–11 (34 years average). Despite this decrease in the cropland area, the production of rice, as discussed in the preceding sections, increased over the years. Consistent policy framework, public investment in technology, rural infrastructure, and human capital has largely benefitted this sector (WB 2016). Cultivation of HYV of rice, increased irrigation coverage, effective use of fertilizers, controlled use of pesticides and better weather forecasting have also contributed to the protection and production of rice.

The irrigation coverage, mainly using groundwater, has increased from 4.19 mha in 2000 to 4.88 mha in 2005, 5.18 mha in 2010 and 5.5 mha in 2015 (FAOSTAT 2021). The use of fertilizers (nitrogen, potash, phosphate) has steadily increased over the last few decades. Historical data on pesticide use is not available, but limited data available from FAOSTAT (2021) reveals that the use of pesticides has increased dramatically since the late twenteeth and early twenty-first centuries. However, the rate of pesticide use has become constant for the last few years. Bangladesh government is promoting the Integrated Pest Management (IPM) and there is much scope for further improving the crop productivity with lesser, if not without, pesticide use through adoption of crop diversification, stringent regulation, and effective IPM implementation (Rahman 2013). In fact, Rahman and Anik (2020) estimated that mean agricultural production efficiency is 0.74 and can be further improved by efficient resource (average farm size, crop specialization, and investment in R&D) allocation.

5.2 *Potential of Fish Production*

It has been discussed earlier that inland capture, culture, and marine fisheries production have increased over the years. Analysis of the fisheries data shows that culture fisheries have a remarkable growth over the last four decades, between 1983–84 and 2013–2014, while capture fisheries, as a percentage of total fish production, have sharply declined over the same period (Fig. 6). Sources of capture fisheries include Sundarbans, wetlands, Kaptai lake, rivers and estuary, and the floodplains. The floodplain fish production has increased between 1983–84 and 2013–14. Since then, the annual growth has been very low (0.34% in 2017–18). The floodplains here include flood lands, including small canals around paddy fields and haor areas (DoF 2018). It is anticipated that blockage of the natural fish migration pathways from the rivers to the floodplains, natural habitats, and the breeding grounds due to development activities has resulted in these lower growth rates. Floodplains connected to the river systems usually have higher fish productivity (in terms of both catch and species diversity) per unit area than those that are disconnected (Craig et al. 2004; Opperman et al. 2013).

Bangladesh Government has taken result-oriented programs to further boost fish production, and for sustainable fisheries management, recognizing its contribution to the national economy and food security. An example of such efforts is the government initiative to increase Hilsha production in Bangladesh. Following the consistent lower yield of Hilsha (Fig. 6), which is the national fish of Bangladesh, in the '90s, the Government adopted a unique coordinated management program named "Hilsha Fishery Management Action Plan (HFMAP)" to protect juvenile Hilsha (locally called Jatka) and brood Hilsha in 2003. The project aimed at establishing sanctuaries, protecting juvenile and brood Hilsha, eliminating the use of harmful fishing gears, providing support (food and alternative income generating activities) to fishers

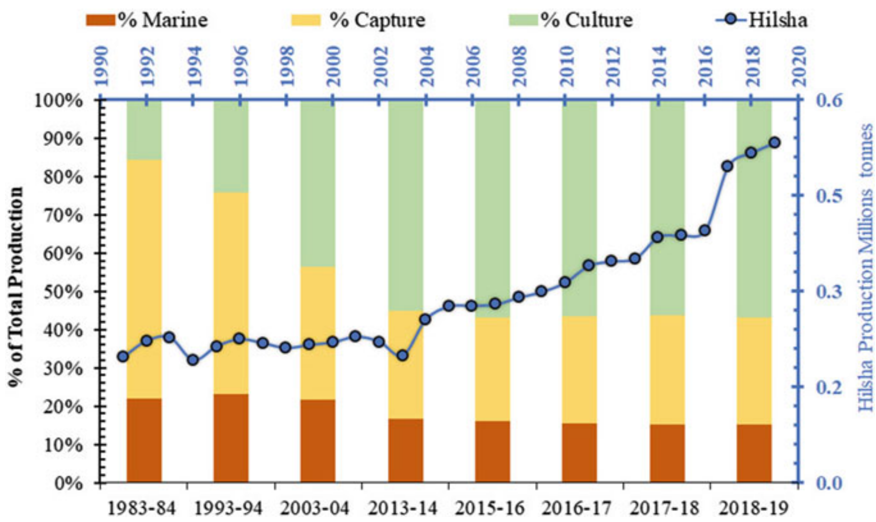

Fig. 6 Fish production in different sectors. *Source* DoF (2018), DoF (2019) and historical Hilsha production in Bangladesh. *Source* DoF (2018), DoF (2019), Rahman et al. (2018)

to cover the ban period. This saw an immediate benefit of increased Hilsha production at 5% p.a. till 2015 (Rahman et al. 2020). The Department of Fisheries and WorldFish jointly implemented a project, shortly titled as ECOFISH-Bangladesh, during 2014–2019 to further enhance the annual incremental Hilsha production. The co-management interventions adopted in the latter project resulted in additional 6% annual incremental production of approx. 130,000 tons Hilsha, worth about US $1040 million (assuming US $8 per kg of Hilsha), over the last 3 years (Rahman et al. 2020). It is estimated that annual Hilsha production can be increased to 0.8 million tonnes with further management and protection. A similar protection approach was taken to save the brood fish at the Halda river.

The main objective of the fisheries sub-sector, as outlined in the 8th Five Year Plan (8FYP) of the Government of Bangladesh, is to "*support sustainable growth in fish and shrimp production with other aquatic resources*" (GED 2020a). One of the ten special initiatives of 8FYP aims to conserve the environment and biodiversity. Key opportunity areas for ensuring sustainability and integrating NbS within this plan are the restoration of fish habitats, establishment of fish sanctuaries, revival of fish biodiversity, utilization of floodplains, etc. Some of the key future strategies that are very much in line with the NbS approach for sustainable fisheries growth, outlined in the BDP-2100, are the restoration of habitat and its connectivity for fish migration, protection of brood fish, their habitats and spawning grounds, establishment of sanctuaries for the conservation and improvement of fish biodiversity and seasonal banning on fishing activity. In many cases, the physical structures fail to perform the function it is meant to, resulting in benefits to the ecosystem. For example, embankment failure during flood events allows riverine fish species to migrate to the floodplain croplands, wetlands, ponds, and canals. "Hard measures," e.g., regulators, which is a blockage to natural fish migratory route, may be inevitable in many circumstances. Such structures can be improvised using elements such as "Fish Pass" to allow for the migration of fishes to and from the controlled area, as recommended in the 8FYP. Fish passes have already been installed in a number of places in Bangladesh and are running successfully. The success of increasing the Hilsha production by adopting "soft measures" suggests that the floodplain as a whole still has a lot of potential for further inland open water (capture) fish production by adopting nature-based solutions. The increase in capture fish production with NbS, similar to that followed for Hilsha and in Halda river, would reduce, if not eliminate, the dependency on culture fish production, which in turn would reduce the stress on the land and water required for culture fish production.

6 Discussion

Although the current study primarily focused on rice and fish as examples, it can be understood that agricultural production in general increases in floodplain ecologies (Rahman and Anik 2020). From an ecological stand, floodplains remain in the second position considering their per hectare value to the society (Costanza et al. 1997).

Sheaffer et al. (2002) estimated that the costs of replacing the goods and services provided by each hectare of a functioning floodplains is approx. US $150,000. A more recent study by Costanza et al. (2014), estimated that the total global ecosystem services, in 2007, is approx. $125 trillion/yr. Often the adverse impacts of floods are highlighted to such an extent that the benefits of floodplains, in agricultural production, at least in Bangladesh, are merely recognized, and very often ignored altogether.

There is an increasing market demand for fruits and crops that are organically cultivated without the use of pesticides and chemicals, and farmers have started responding to those needs. An example for this can be the mango orchards in the north-west, south-west, and eastern hilly regions where different varieties of mangoes are being produced organically. In line with this, the Perspective Plan of Bangladesh 2021–2041 has also emphasized upon the production and increased use of bio-fertilizers in agriculture. The government has banned the commercial import and selling of formalin which was being used for market products, as well as promoting the efficient use of fertilizers and pesticides through implementation of IPM. Increasing the use of surface water sources for irrigation and crop diversification is suggested in government policies and strategies to reduce groundwater usage in irrigation, thereby conserving the environment (GED 2020b; NAP 2018; NEP 2018). The agricultural diversity and productivity can be further enhanced through research and technology development for HYV of different crops, sustainable management of natural resources in floodplains, and by adopting agro-ecologically suitable and climate-smart agricultural practices (BDP-2100 2018). Re-establishing the floodplain connectivity and increasing floodplain agriculture through the efficient utilization of floodplain friendly systems and flood water would reduce stress on the groundwater system, as well as promote sustainable NbS and green revolution in the agriculture sector.

7 Conclusion

In 2015, the member states of the United Nations adopted 17 goals, collectively known as the "Sustainable Development Goals" or the "SDG" for the betterment of people and the planet as a whole. Target 2.4 of Goal 2 states that "*By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*" (SDG 2015). This clearly emphasizes on the need for sustainable growth of agricultural produces while maintaining the balance of the ecosystem. In the context of Bangladesh, the supply of local agricultural produce has responded to fulfill the present demand and is expected to match the future demands as well. However, care must be taken to ensure that increasing food production and enhancing economic development does not result in exhaustively depleting natural resources. Productivity should be maximized while preserving the integrity of the ecosystem in general, and the floodplain to be specific. Therefore, if sustainable development of the floodplain is not prioritized it could result in severe ecological and cultural damages (Haque 1993).

Current projections show that the demand for the next two decades can be met with the present agricultural growth rate. However, it is still crucial to adopt NbS in order to ensure sustainable growth of agricultural produces in all sectors during that period and beyond, and Bangladesh has already initiated the process. Taking this course of action will not only ensure food security for the coming decades but will also contribute towards preserving the environment and ecosystem as a whole.

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The Role of Tropical Forests to Support Food Sovereignty Owing to the COVID-19 Pandemic

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1 Introduction

The necessity to quadruplicate food production in the coming decades, particularly due to the high food demand from developed countries, is a serious challenge for global food security (Godfray et al. 2010). Pretty and Bharucha (2014) argues that chemical inputs, genetic engineering, and mechanization are among the reasons for higher food demand. Conventional agriculture has been the major source of many social and environmental issues, including climate change, biodiversity destruction and integration, land depletion, water shortages, and social structure disturbance (Godfray et al. 2010; Pretty and Bharucha 2014). Thus, a broad consensus is shifting from yield-based to multifunctional agriculture, in which sustainable intensification complies with more general societal and environmental goals (Pretty and Bharucha

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2014; Waldron et al. 2017). Agroforestry is one of the most multipurpose agricultural forms in physical and human geography (Waldron et al. 2017). Recent data indicates that agroforestry can improve agricultural yields through appropriate crop types and local conditions, and the degree of expertise is frequently studied for environmental advantages and peasant farmers' organizations (Pretty and Bharucha 2014). Indonesia is the seventh-largest country in Asia and the third most populous country in the world, with over 267 million people in 2018 (World Bank 2021). Indonesia has extensive tropical forests and is rich in biodiversity, with supportive fertile soils, rainfall, temperature, humidity, climate, and the optimum organic cycle throughout the year. Moreover, as a tropical country with two seasons (wet and dry season), Indonesia has a comparative advantage in agriculture in which farming can be done throughout the year. Nevertheless, despite the food potential, variety, and production, the country's food security and sovereignty are among the lowest in the world.

Indonesia has been transformed from a low- to middle-income country as indicated by the gross national income per capita of US$ 4,050 in 2019 and an average growth rate of 5% per year (World Bank 2021). The middle class, at least 52 million people, greatly contributes to economic growth (World Bank 2021). However, Indonesia is burdened by three types of malnutrition: stunting and wasting, obesity, and micronutrient deficiencies (Sparrow et al. 2020; Arif et al. 2020). Malnutrition and over nutrition simultaneously lead to increased non-communicable diseases, decreased mental and physical quality, and decreased overall quality of life (Sleet 2020). Yet this condition occurs in various low-and middle-income countries (Lee et al. 2012; Popkin 2001; Subramanian et al. 2009).

The world is currently facing SARS-CoV-2 (COVID-19). The COVID-19 pandemic affects more than just the health, education, and socio-economic sectors but also the Sustainable Development Goal (SDG) 2: "Zero hunger" (Bloomberg 2020; Khorsandi 2020). The World Health Organization (2020) warns about the upcoming global food crisis. Lockdown, social restrictions, and travel bans as the efforts to prevent the spread of COVID-19 have affected business and societal activities (Darma et al. 2020; Ilmi et al. 2020), physical and economic access to food (Devereux et al. 2020), food security (Sparrow et al. 2020; Erokhin and Gao 2020), and nationalism (Handayani 2020).

The COVID-19 pandemic has posed a danger to global food supply and security, particularly for the emerging and food-dependent countries in the global food market. In Indonesia, the national supply of staple food mainly depends on the vulnerable world rice market. The COVID-19 pandemic has alarmed all countries to strengthen national food security and sovereignty. Suppose that there will be import prohibition and restriction while imported food is the primary source of the national food system, it potentially threatens the national food security and sovereignty. Meanwhile, the dominance of rice has disrupted food diversification, setting aside prospective local foods from tropical forests. This chapter discusses the role of Indonesia's tropical forests in supporting food security and sovereignty in the era of the COVID-19 pandemic.

2 Material and Methods

This chapter is written using a descriptive-analytical methodology in conjunction with qualitative research methods. The qualitative approach searches for relative, hermeneutic, and interpretative truths (Brown 2010). This study summarizes the findings of the study of tropical forests in food sovereignty, COVID-19, and the variables studied accurately. Interviews, field observation reports, transcripts, journals, observation notes, data collection, and analysis were conducted simultaneously and integrated (Mulyadi 2011).

The data analysis strategies applied in this study include collecting data, reducing data, presenting data, and drawing conclusions (Miles and Huberman 1992). Triangulation of sources and methods is used to ensure data veracity (Creswell and Creswell 2017). In addition, it also ensures data integrity, namely a credible test for data validity that involves evaluating data from many sources using the same procedural approach.

3 Results and Discussion

3.1 Food Sovereignty and the COVID-19 Pandemic

In fact, rice is the primary staple food for approximately half of the world's population, particularly the Asians. It is cultivated in 113 countries, although only a few countries are categorized as the largest producers. China and India supply half of the global rice demand, while the rest is supplied by Indonesia, Bangladesh, Vietnam, Thailand, and Myanmar (FAOSTAT 2017). Considering small farmers account for about 80% of rice production, socio-economic issues become seriously debatable. According to Greenville (2018), annual rice consumption per capita in Indonesia is 135 kg, higher than Philippines (115 kg), Thailand (99 kg), and Malaysia (81 kg).

In Indonesia, food is associated with rice. In election or political campaigns, politicians frequently use rice production (Davidson 2018; Firdaus et al. 2008), populist economy, rice self-sufficiency (Aspinall 2016), food unity (Neilson 2018) as a political issue. Rice self-sufficiency is a heated debate in every Indonesia's presidential election. Therefore, policies related to rice farming and trading have always been a priority for the Indonesian government.

In fact, the impact of rice prices on poverty is lucid. The rise in the rice price in Indonesia has contributed to the higher poverty rate as low-income families use a significant part of their income for food. It also occurs in other developing countries. The rise of rice price in Bangladesh is about 10%, adversely affecting the net income of the poorest half of the population (Sayeed and Yunus 2018). Meanwhile, a 10% rise in food costs led to a 2.2% increase in poverty in Liberia (Tsimpo and Wodon 2008). As a vital commodity, the scarcity and high prices of rice may exacerbate poverty and hunger. Therefore, government must make every effort to ensure the availability and affordability of rice in the domestic markets.

After the Second World War, many newly independent countries made food self-sufficiency a priority, including Indonesia. Self-sufficiency is focused on supplying domestic products and reducing foreign commerce, whereas food security is focused on the availability of local resources (Tortajada and Zhang 2017). However, the significant growth in food consumption and food production becomes a barrier to realize food self-sufficiency and sovereignty.

The notion of food security is utilized to address the rising need for imported food, regardless of who produces the food or where it is produced. As an illustration, in 2018, Indonesia has greatly depends on imported onion by 95%, imported beef by 24%, and imported sugar by 55% (McDonald and Meylinah 2019; Ministry of Agriculture 2020). Essentially, there are two key components of food security, namely economic access (the money to buy food) and physical access (the availability of food) (Patel 2009). Based on the concept of food security, a country can achieve food security by ensuring food availability at the household level, even by importing food if required. Initially, the food security strategy is focused on stockpiling food to avoid starvation (Baer-Nawrocka and Sadowski 2019). Nevertheless, when domestic production falls, importing food is the only way to overcome food shortage. This situation is unfavorable since many food markets are "thin markets," which are associated with price fluctuations and external dynamics.

Furthermore, the concept of food self-sufficiency emerges as the countermeasures against the dependence on food imports, and instead to promote local resources. *Food independence* is defined as the ability of a nation to ensure that all its residents obtain sufficient, good quality, safe, and halal food, based on the optimization of utilization and local resources (Nurrachmi 2017; Gubarkov et al. 2021; Koroleva 2021). The five components in food self-sufficiency are adequate availability, stability, affordability, good quality/safety of food, and independence from external parties. These components are required to realize resilience against either global economic growth or crisis. However, the concept of food self-sufficiency excludes community engagement and community welfare activities, giving rise to the concept of food sovereignty (Gubarkov 2021; Sampson et al. 2021).

Food sovereignty, in principle, encompasses a wider range of issues than food security and food self-sufficiency (Cahyono 2013). The concept was first introduced by an international farmer organization called La Via Campesina at the World Food Summit (WFS), November 1996, in Rome, Italy (Seminar et al. 2018). They contend that the concept of food security campaigned by the Food and Agriculture Organization (FAO) and other international institutions is unfair for the developing countries hence an alternative called food sovereignty is proposed. *Food sovereignty* is defined as the right of the people to determine particular policies and strategies for the production, distribution, and consumption of sustainable food to ensure the right to food for the entire population, based on small-and medium-scale production while respecting peasant' culture and diversity (Sampson et al. 2021).

Principally, the concept of food security provides an ample space for markets, allowing farmers to have sovereignty over their land. A step toward food security has been initiated by the government in Central Kalimantan, Merauke, East Kalimantan, North Kalimantan, and North Sumatra through food estate program to meet domestic food requirements (Santosa 2014; Saribanon et al. 2016). However, food estate is deemed to be more agribusiness and less community involvement (Kamin and Altamaha 2019; Dwiguna and Munandar 2020). While farmers are able to participate in food estate programs, they also become very dependent on other parties in producing, distributing, and consuming foods. For the reason of efficiency and productivity, large companies control all agricultural facilities. The intellectual property rights system provides privileges for large companies to monopolize over an industry that should belong to the broader community, thereby allowing them to monopolize genetic material and life forms such as livestock seeds and germs. This system prohibits the free exchange of livestock seeds and agricultural seedlings between large companies and farmers, but on the contrary, it allows large companies to utilize farmers' knowledge.

The COVID-19 pandemic causes the decision-makers to implement socio-economic activities with certain restrictions or lockdowns that affect all aspects of life. Food security, particularly, faces significant impacts. First, restrictions on activities cause decline in food production due to limitations in agricultural labor and the distribution of agricultural inputs and finance. As the implication of the decline in food supply and stock is the rising food prices, changes in food consumption patterns, and social unrest. Second, restrictions on activities disrupt transportation and logistics, hindering the food supply chain, reducing access to food, and increasing food loss and waste. This situation limits the access to food and reduces agribusiness profits. Consequently, there is an increase in logistics costs, a decrease in fresh and processed food intake, and a decrease in the welfare of the agricultural sector. Third, restrictions on activities caused unprecedented job losses, increased unemployment, reduced production and productivity, and income disruption. This condition leads to increased poverty, accompanied by reduced purchasing power, low balanced food intake, and decreased immunity. Fourth, social/physical distancing causes a decrease in food expenditure and an increase in sanitation and health-related expenditure, which results in low and unbalanced nutritional intake. Finally, restrictions on activities cause the economic crisis, malnutrition, stunting, hunger, micronutrient shortages, and low body immunity. This condition leads to higher dependence on imported foods, threatening food security and food sovereignty. Unfortunately, COVID-19 has made many food-producing countries prioritize their national interests and sell their food expensively.

The COVID-19 pandemic seems to recall the importance of tropical forests on food sovereignty and food diversification. However, malnutrition, obesity, and unbalanced nutrition are mainly caused by an imbalance in food intake and a lack of micronutrients. Tropical forests provide considerable diversity in food, vitamins, medicines, and micronutrients that can increase the body's immunity against the threat of COVID-19.

3.2 Forest and Agriculture in Food Sovereignty

The agriculture's interest and forestry's interest often conflict because of differences in paradigm and management, especially in food. On one side, agriculture becomes the backbone for food fulfillment with its extensification and intensification. However, agriculture becomes the reason for tropical forest conversion into high productivity monoculture agriculture, creating several problems such as reduced carbon sequestration, carbon emissions, land degradation, and erosion. The global food system adversely affects the environment on a vast scale and contributes to climate change.

On the other side, forestry is identical to timber production, wildlife, natural scenery, conservation, and minimal use. Tropical forests are also the source of food, medicine, fiber, and other essential products. Vinceti et al. (2008) mention some foods from tropical forest, among others (1) leaves, (2) fruits and seeds, (3) palms, (4) roots and tubers, (5) fungi, (6) several insects, (7) from mangroves (fish, crab, shrimp) and (8) animal feed. Indonesia's tropical forests cover a total area of 143 million hectares and are claimed to have mega-biodiversity that are beneficial to human life in the forms of 77 sources of carbohydrates, 26 types of nut, 75 sources of oils and fats, 389 seeds and fruits, 228 vegetables, 110 spices, 40 beverage ingredients, and 1260 medicinal plants (Suhardi et al. 2002). This exceptional potential requires the collaboration between the people and government to maintain sustainable forest management for realizing the national prosperity through food sovereignty.

However, there is an adverse effect of living in the forests since they are the sources of many diseases from tropical forests, for example, malaria, HIV/AIDS, Ebola and Marburg viruses, mercury poisoning, trypanosomiasis, onchocerciasis, yellow fever, and leishmaniasis (Colfer et al. 2006). Apart from causing environmental issues, deforestation also results in the loss of natural foods and promotes the spread of disease (Dounias and Froment 2011). Tropical forests are the main food source for local people as they provide nuts, fruit, shrubs, roots, fungi, and animals. Tropical forests also provide animal feed and firewood for cooking. In the future, it is predicted that tropical forests will have an important role in plant breeding and genetic engineering. Tropical forest biodiversity is a source of a genetic bank for future quality crop products, which are potential to generate superior plant seeds for food sovereignty. In addition, forests provide food during the famine, crisis, and war, thus becoming a safety net. Nonetheless, forests can be a poverty trap because they often exclude forest dwellers from the development process, deterring them to earn a living. Consequently, they rely heavily on forests as a food source. This reality, however, can show types of food with profound implications for wildlife and humans.

The issue related to forest food is the guarantee of healthy and proper processing. Some foods can threaten human health. For example, a small amount of cyanide in cassava, and aflatoxin in corn. The handling of wild meat might lead to the spread of virus-caused diseases. In addition, the demand for natural, seasonal foods may trigger food abundance and shortage. The uneven distribution of food within the family often raises the risk of malnutrition and illness.

Handayani (2010) reported 62 plant species in the Gunung Simpang Nature Reserve forest were used by the local community for edible purposes. The Baduy community consumed 240 plant species from the forests around them (Hidayati 2013). Meanwhile, Damora et al. (2008) reported that in the Community Forestry of West Lampung Regency, farmer families consumed 85.2 g plant-based food per capita per day.

Apart from being food providers, forests also increase farmers' household food access through additional income. However, food access is gained through the control over food as the result of people's purchasing power or income (Maxwell and Frankenberger 1992; Apriyanto et al. 2016).

Tropical natural resources involve high biomass productivity, despite their relatively low economic value (Agus 2018). Proper bio-geo-resources of land (soil, water, and mineral) and biology (flora, fauna, and human) through an integrated bio-cycle farming system can support healthy food sovereignty and renewable energy (Agus 2013).

Extensification, intensification, and diversification of food production in forestlands should play an essential role in supporting food security and sovereignty, which ultimately overcome hunger and malnutrition. Moreover, agroforestry systems can bridge agriculture's and forestry's interests for food security during the COVID-19 pandemic.

In Indonesia, the practices of agroforestry have been carried out for a long time (Foresta and Michon 2000) and were previously known as cultivation practices (Sabarnurdin 2010). The practices include shifting cultivation and parrots limbo, intercropping, yards, *repong*, mixed gardening, *talun*, and others. Some farmers practice traditional agroforestry while others prefer a modern one. In addition, agroforestry systems have long supported sustainable food sovereignty (Butarbutar 2009).

Agroforestry provides significant contributions to food sovereignty. The contributions include: (1) providing life support and buffer for the agricultural system by regulating water management, nutrients, microclimate, and carbon sinks required by monoculture agricultural systems, (2) producing various edibles, animal feed, livestock products, and agricultural products that support food sovereignty, (3) providing germplasm and particular edibles for the food industry, agricultural seeds, and livestock seeds, (4) providing local knowledge and local wisdom, especially in traditional agroforestry for agricultural development, distribution, and culture, and (5) providing biopharma and bio cosmetics products that cannot be duplicated by modern industry (Cahyono 2013).

Food sovereignty allows farmers to determine a proper sustainable agricultural system. A sustainable agricultural system should be well-balanced in terms of ecology, economics, environment, and humanity, for today and the future. The basic principles of a sustainable agricultural system include ecological, socio-economic, technical, and political principles. Among its characteristics are economic viability, ecological soundness and friendliness, social justice, cultural appropriateness, and holistic system and approach. Its application entails integrated pest control, rotational systems, grass cultivation, land conservation, water quality maintenance, protection crops, diversification of crops and land, plant nutrition processing, and agroforestry. In addition, an integrated agricultural system is necessary to ensure food security and sovereignty.

3.3 The Role of Tropical Forests for Food Sovereignty During the COVID-19 Pandemic

The contribution of tropical forests in supporting food sovereignty can be indirect or direct. Indirectly, the forest serves as a life-supporting system, which supports the agri-food system. This contribution is related to forests as water regulators, microclimate regulators, carbon sinks, and the source of germplasm. Forests are direct providers of various types of vegetables, fruits, seeds, tubers, and starch, as well as the source of carbohydrates, protein, and vitamins. They also provide various animal protein sources, such as deer, bulls, porcupines, moles, pangolins, cassowaries, and various types of birds.

3.3.1 Support Living Systems

Forests provide various supporting life systems such as diverse food, water, oxygen, nutrients, germplasm for human life and the environment (Başkent et al. 2011; Kotwal et al. 2008; Turner et al. 2011). For example, the forest may provide food in the form of fruit, seeds, tubers, starch, and vegetables as a source of carbohydrates, protein, and vitamins, as well as animal food in the form of deer, bulls, porcupines, moles, pangolins, cassowaries, and various types of birds as sources of food from animals.

3.3.2 Food Sources

The diversity of trees and tropical forest wildlife (flora and fauna) is the source of food security and sovereignty. Forests are the source of healthy affordable foods, especially for those with limited livelihoods, during food scarcity amidst crop failures, economic crises, and pandemics. Tropical forests also provide a variety of animal-sourced foods and medicinal plants. Various wild animals, honey, insects, and medicinal plants are available in the forest. A healthy forest ecosystem will provide a diverse and balanced food supply for humans and the environment. Food safety requires not only a sufficient amount of calorie intake but also variations in balanced nutritional intake. The study of Jansen et al. (2020) proves the significant contribution of tropical forest trees to food security and nutrition despite the lack of knowledge about them.

3.3.3 Source of Nutrition

Tropical forests are arguably the source of various nutrient contents (especially micro-nutrients) and high-quality foods (Baudron et al. 2019). They provide foods rich in phytochemicals, which are beneficial for health. Forest honey contains active compounds such as flavonoids, alkaloids, saponins, and triterpenoids, which serve as inhibitors, antibiotics, antimicrobial, and antiparasitic (Adalina 2018). Rasolofoson et al. (2018) suggest that the growth of children exposed to various forest foods is better than those who do not gain the opportunity. The diversity of macronutrients and micronutrients and other compounds in forest foods can be used to help alleviate micronutrient deficiencies and malnutrition by fulfilling food needs for humans (Ickowitz et al. 2016).

3.3.4 Food Price Stability

Rural communities' access to both food and non-food forest products provides economic sustainability as well as healthy and high-quality foods to reduce dependence on food from external parties (Baudron et al. 2019). In addition, it supports price stability as it is influenced by neither long distribution chains nor world food markets, especially in the context of utilization of forest products by local communities (Vinceti et al. 2013).

3.3.5 Food Sustainability

Forests are the natural habitat for various essential pollinators for food production, such as birds, insects, and bees. It is the indirect but essential role of forests in food security. Pollinator decline due to damage to natural habitats will cause problems for the sustainability of food production, which can interfere with food security and sovereignty (Andriyana 2021). Other vital services provided by forest ecosystems for agriculture are nutrient cycle services, water management, and climate change mitigation (Dollinger and Jose 2018; Junaidi and Indrajaya 2018; Abbas et al. 2017). The availability of various life ecosystem services ensures the continuity and diversity of food production.

3.3.6 Forest for Food and Energy

Forest is the source of food, ecosystem services, and energy. It is demonstrated by the importance of fuelwood from the forest for many local communities. During fuelwood scarcity, local people are forced to spend more energy and time to collect fuelwood far away (Sunderland et al. 2013). Consequently, fuelwood scarcity can change local people's cooking practices and other habits through the efficient use of fuelwood and exploration of alternative energy sources (Rahman et al. 2019; Catacutan et al. 2017).

3.3.7 Access to Food

The state's respect for the rights of local communities regarding forest access and management is the first step in the strategy for achieving food security and food sovereignty (Nurfatriani and Alviya 2019). Over the past five years, the Indonesian government has made massive and structured efforts through community-based forest management programs, including Social Forestry (Lingkungan and dan Kehutanan 2020). Approximately 12.7 million hectares of the state forest area have been opened for the community (Daryanto. 2018). However, due to the significance of forest sustainability, legal instruments and assistance related to forest sustainability are needed (Lingkungan and dan Kehutanan 2020; Agung et al. 2018). Moreover, community education on the importance of forest sustainability in food security is also required. In addition, local wisdom needs to be incorporated in the implementation of forest management in social forestry programs (Firamadhani et al. 2020; Setiawan and Qiptiyah 2014).

4 Conclusions

Indonesia has a very high potential for food productivity and diversity but low food sovereignty. The COVID-19 pandemic urges the government to restrict the civilians' activities, threatening global and national food production and security. Limitations in agricultural labor and the distribution of agricultural inputs and financing have led to a decline in food production. As the implication of the lower food availability and stock is the higher food costs, shifts in food consumption habits, and social discontent. Moreover, activity restriction impacts transportation and logistics, obstructing the food supply chain, limiting food access, and increasing food loss and waste. Activity restrictions also resulted in unprecedented job losses, increased unemployment, reduced production and productivity, and lost income. Finally, the activity restrictions lead to economic catastrophe, malnutrition, stunting, starvation, nutritional deficiencies, and low bodily immunity.

Extensification, intensification, and diversification of food production on forestlands potentially support food diversity, food security, food sovereignty, and resolve hunger and malnutrition. Forests serve as water regulators, microclimate regulators, carbon sinks, and germplasm sources, all of which contribute to food security. Forests are the source of carbohydrates, proteins, and vitamins in the form of vegetables, fruit, seeds, tubers, and starch. They also provide complete sources of protein derived from deer, bulls, porcupines, moles, pangolins, cassowaries, and various birds. Forests are an essential complement to traditional agriculture to create a landscape of food security and sovereignty to deal with the COVID-19 pandemic.

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Climate Change and Food Security in Pakistan

Naeem Shahzad and Muhammad Amjad

1 Introduction

Climate change is described as "a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (Seyboth 2013). It also refers to "periodic modification of Earth's climate brought about as a result of changes in the atmosphere as well as interactions between the atmosphere and various other geologic, chemical, biological, and geographic factors within the Earth system" (Jackson 2021). In another definition, "any change in climate over time whether due to natural variability or as a result of human activity" (Pielke 2004).

Day by day, technological developments have resulted in a better understanding of the global warming issue, which is directly related to climate change. There are indicators in the climate model projections that suggest a rise of further 0.3 to 1.7 °C (0.5 to 3.1 °F) in the Earth's temperature (Stocker et al. 2013). The dynamism in climate displays spatial and temporal variability. Changes in the climate result in more frequent extreme weather events, such as heavy rainfall and heavy snowfall; droughts, heat waves, ocean acidification; and extinction of certain species. Some of the other effects include rising sea levels, increasing temperature of the world, precipitation change and extension of deserts in the subtropics. As a result of climate change, decreased crop yields, threats to food security and migration from populated areas due to flooding directly affect human existence on the planet earth (Raza et al. 2019; Shahid and Al-Shankiti 2013).

In 2014, the Intergovernmental Panel on Climate Change (IPCC) concluded that nearly 99% of climate change is due to anthropogenic (human) activities, which lead to a greater concentration of greenhouse gases in the Earth's climate. The irreversible

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nature of impacts caused by climate change makes it even more alarming for the continuation of life on the planet. For the individuals at the helm of affairs, this understanding is very important to take the right direction at the right time to undo the effects of climate change before it becomes too late. The issue is, unfortunately, complex, while several gray areas and unsolved puzzles need special deliberation for further research.

The phenomenon of global climate change seriously affects many countries throughout the world, including Pakistan. The country is highly prone to various disasters due to its typical bone-dry terrain profile and stressed resources. Between 1929 and 2005, the time between disaster occurrence decreased, from 56 years in 1929 to only 5 years in 2005 (Kitchi 2017). Avalanches, storm surges, landslides, floods, droughts, cyclones, heat waves, dry spells, and vector-borne diseases are just a few of the hazards that the country is susceptible to. Pakistan has continuously ranked among the list of most affected countries recurrently affected by disasters, both in the long term and every year index (Eckstein et al. 2019). In addition, Pakistan is plagued by a variety of vector-borne diseases, including Jungle Fever, Crimean-Congo, Haemorrhagic Fever, Dengue, Haemorrhagic Fever, West Nile Infection, Japanese Encephalitis, and Scour Typhus, due to its subtropical location and climatic suitability for vectors (Ali et al. 2021; Sugamata et al. 1987).

Climate change has a direct effect on water security. Water security inspires all dimensions of human health and well-being and is fundamental to both food and energy (Marttunen et al. 2019). Water is directly related to food security (Malhi et al. 2021; Shahid and Al-Shankiti 2013). Owing to the food and water nexus and due to around 90% agricultural water usage in the region, different narratives are prevalent. Subsidized electricity for water pumping is now considered unmanageable in India. The relationship between energy and water is viewed through the lens of untapped hydropower potential in Pakistan and Nepal, whereas infrastructure is the main priority in Bangladesh. Another dispute highlights mismanagement blames both upstream and downstream (e.g., Afghanistan and Nepal), with each upstream riparian country blaming their downstream riparian for water losses. The growing water scarcity issues across the region may further lead to food insecurity in the near future if significant measures and steps are not taken to tackle this issue.

2 Historical Climate Metrics and Projections

2.1 Metrics

The impacts of climate change are quite obvious and can be easily observed in the changing patterns of precipitation, weather and related events, as shown in Fig. 1. Some of the evidence of climate metrics (“IPCC 5th Assessment Report “, 2013) is as follows:

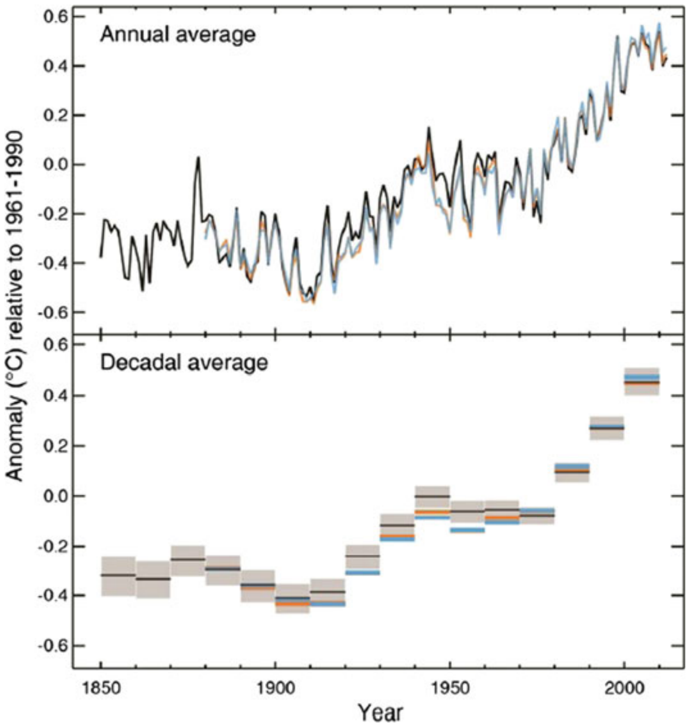

Fig. 1 Land and ocean surface temperature 1850–2012 ("IPCC 5th Assessment Report" 2013)

- It has been concluded with certain evidence from research studies that the three decades after 1983 were the warmest 30 years of the last 1400 years.
- The warming of the Upper Ocean from 1971 to 2010 has been claimed by scientists with high confidence since this warming accounted for 90% of the energy accumulation during this period.
- Scientists are certain that for the last two decades, Antarctic and Greenland ice sheets have been losing mass. Moreover, there has been a decline in the Northern Hemisphere spring snow cover and Arctic Sea ice.
- The observed sea level rise after the 1950s has been found to be higher than the average rise in sea level over the previous two millennia.
- Across the globe, the amount of greenhouse gases has risen to levels not observed on the planet in 800,000 years.

2.2 *Projections*

If uncontrolled emissions of greenhouse gases are allowed to continue, it is perceived that the change in the Earth's climate will also continue ("IPCC 5th Assessment Report" 2013) (Fig. 2).

- Climate change will also change the global water cycle. The disparity between dry and wet seasons will increase in most of the regions, which will trigger a change in dry and wet regions around the globe. Drier regions, in addition to other issues, will lead to decreased crop productivity and food insecurity, while wet regions will aggravate flooding.
- An increase of 1.5 °C in the Earth's surface in most cases is expected by the end of the twenty-first century. However, there is even a chance of a 2.0 °C increase in many cases.
- The warming of the oceans will continue and thereafter with the heat reaching the deep ocean will change the circulation patterns.
- There is a possibility of a decrease in the global glacier volume and snow in the Northern Hemisphere.
- It is quite expected that the rate of rise in mean sea level will exceed that of the previous four decades.
- Acidifications of the oceans will increase due to the increased rate of CO_2 production.
- The surface temperatures are largely determined by cumulative CO_2, showing that the changes in climate will continue.

3 Climate Changes and Its Impacts

The impacts of climate change pose one of the gravest threats to humankind. This has led to the development of a global consensus on this issue owing to significantly visible socioeconomic outcomes for various sectors, including energy use, security, food production, health and natural resource management. These impacts have become obvious with growing intensity, severity, and frequency of extreme weather events such as floods, storms, hurricanes and cyclones and droughts. An upsurge of

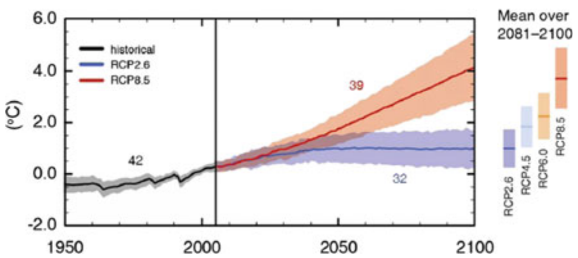

Fig. 2 Global average surface temperature change due to climate change ("IPCC 5th Assessment Report" 2013)

disasters has been witnessed from approximately 125 in the 1980s to 400–500 on average per year (Pachauri et al. 2009; Thomas and López 2015).

The predicted climate change impacts are slowly manifesting, according to the 4th IPCC report. Globally, rising temperatures result in decreased growth rates of crop yield, while an upsurge in climate-induced diseases has also been reported. The accelerating recession of glaciers, transformation in marine ecosystems and rainfall variability are also apparent every passing year. One of the grimmest threats from climate change impacts is the availability of fresh water resources since large river basins are predicted to decline by the 2050s, badly affecting more than a billion people worldwide (Islam and Karim 2019).

Climate change is also expected to have a negative impact on human health. Death rates are expected to rise as a result of increasing heat wave frequency and duration, particularly in locations where people are not used to deal with higher temperatures. Recent heat wave events in Canada are a glaring example. Climate change is also expected to increase the potential transmission of vector-borne diseases such as malaria, yellow fever, and dengue fever, extending the range of organisms that transport these diseases into the temperate zone, which includes Asia, Europe, and parts of the United States (Skendžić et al. 2021).

As a result of an important study on the effects of climate change in South Asia, carried out by approximately 850 experts from more than 80 countries (Lal et al. 2010), the following important points in the context of this region have been highlighted:

- It is a reality that climate change is occurring in South Asia, and these changes are easily identifiable. Common masses can feel this change in the climate.
- In the coming decades, this change in the climate will be more obvious.
- The change in the climate is inevitable.
- There is a likelihood of increased food shortages, more deaths due to heat and an increase in flooding in the areas in South Asia.
- Changes in the climate will have an impact on South Asia's development.
- Development projects that cause less carbon content to be emitted into the Earth's surface are likely to be more cost effective for all countries in South Asia.
- As the countries of the world are locked into interdependence, changes in one country affect the other country. Therefore, climate change will change the resources and commodities at one place, thus changing the trade relations between countries and subsequently the diplomatic relations between them.
- Economic growth will also be affected by changes in the climate.

Pakistan, a country defined by its geography and climatic diversity, is located in the northwestern part of South Asia. Since the turn of the century, the annual mean surface temperature has been steadily rising (Chaudhry 2017). The country is undergoing transformations, shifting from a predominantly rural village culture to a modernised, administratively based, and metropolitan economy. People who have lived in disaster-prone locations for a long time usually have mechanisms in place that allow them to recognize and moderate the disaster risks that surround them. As communities relocate or are forced to relocate to metropolitan areas, an increasing number of predominantly poor communities live in hazard-prone locations, with little acquaintance with the nature of the hazards that surround them (Kitchi 2017). A high pace of urbanisation feeds into this trend, prompting earth-harming practices such as unregulated logging or overgrazing, which may exacerbate and alter existing risk patterns. Climate change will make it more difficult to adapt monsoon and precipitation patterns, resulting in more intense and less predictable flooding and dry season occurrences.

Climate change policy was articulated in 2012 in light of Pakistan's significant vulnerability to these negative effects. The goal of this policy is to encourage all stakeholders to adapt and advocate for mitigation. Various sectors (water, agriculture, forestry, livestock, coastal belts, ecosystems, and biodiversity) are especially vulnerable to climate change effects, as underlined in this policy, while the adaptation solutions are discussed in depth. (Kitchi 2017). Although Pakistan contributes minimally to global greenhouse gas (GHG) emissions, its contribution to mitigation and adaptation is widely recognized.

4 Methodology

This study focuses on the secondary literature to review the prevailing conditions of Pakistan in the context of changing climatic patterns directly affecting different vistas, including food security. A rich body of knowledge, including journals, books and reports, has been explored to ascertain and discuss in detail the growing climate change impacts threatening the country, thereby suggesting a way forward to deal with this imminent threat.

5 Discussions

5.1 Vulnerabilities of Pakistan to Climate Change

The accompanying climate change-related risks have heightened Pakistan's survival awareness, particularly in relation to the national security of sectors such as water, food, and energy. Global climate models (GCMs) and nested regional climate models (RCMs) were used to simulate large-scale patterns of climate change. In the arid regions of Pakistan and northwest India, the RCM forecasted the greatest reductions (precipitation dropped to 1 mm/day; 60% decline in soil moisture) (Hassell and Jones 1999; Lal et al. 2000).

Table 1 demonstrates the sensitivity of important sectors to climate change consequences (McCarthy et al. 2001). The vulnerability of Pakistan, which lies in South Asia, ranges from moderate to high with a confidence level of medium to high, which

Table 1 Vulnerability of key sectors to impacts of climate change for subregions in Asia

Region	Food and fiber	Biodiversity	Water resources	Coastal ecosystem	Human health	Settlements
Boreal Asia	+1/H	−2/M	+1/M	+1/L	−1/L	0/M
Central Asia	−2/H	−1/L	−2/H	−1/L	−1/M	−1/M
Tibetan Plateau	0/L	−2/M	−1/L	n.a	No data	No data
Temperate Asia	−2/H	−1/M	−2/H	−2/H	−2/M	−2/H
South Asia	−2/H	−2/M	−2/H	−2/H	−1/M	−2/M
Southeast Asia	−2/H	−2/M	−2/H	−2/H	−1/M	−2/M

The vulnerability scale is as follows: highly vulnerable (−2), moderately vulnerable (−1), slightly or not vulnerable (0), slightly resilient (+1), and most resilient (+2). Confidence levels abbreviated as H (high), M (medium), L (low)(McCarthy et al. 2001)

is an alarming state for the country. Some of the glaring climate change impacts visible in Pakistan are as follows:

- Substantial increases in the frequency and severity of extreme climate events, as well as unpredictable rainfall downpours causing persistent and intense floods and dry seasons, have a significant impact on agriculture and food security. The flood risks are increasing owing to the increasing surface temperatures contributing to rise in snow line (Singh 1998).
- Antedated depletion of the Hindu Kush-Karakoram-Himalayan (HKH) ice sheets is expected due to rising global average temperatures and carbon dust from trans-boundary pollution sources, posing a threat to water inflows into the Indus River Systems (Bolch et al. 2019).
- Increased siltation levels in existing dams are paving the path for more frequent and catastrophic floods (Atkins 2013; Roca 2012).
- Escalating temperatures are causing more heat and water scarcity, particularly in dry and semiarid areas, resulting in decreased agricultural production and increased food insecurity (Raza et al. 2019).
- Excessively rapid changes in climatic conditions are causing further reductions in officially sparse forest cover, allowing for natural translocation of negatively impacted plant species (Seneviratne et al. 2012).
- Increased tendency of saline water intrusion in the Indus delta, negatively affecting beachfront horticulture, agriculture, mangroves, and fish breeding grounds (Siyal 2018).
- Coastal zones are at risk due to rising sea levels and increased cyclonic activity due to warmer ocean surface temperatures (Oppenheimer et al. 2019).
- Growing concerns about sharing water assets between upper and lower riparian areas due to decreasing water availability (Briscoe et al. 2006).

5.2 *Climate Change and Food Security*

5.2.1 Growing Threat to Food Security

Pakistan ranks 12th among the countries expected to be adversely affected by climate change (Ullah 2017). As a predominantly agro-based economy, the country is facing a direct threat to its food security due to global climate change. Food security has several aspects, including production, distribution, and accessibility (Tariq et al. 2014). A large portion of our economy is based on a highly susceptible sector (agricultural), and the majority of the rural population is poor, making them less resilient to climate change-related hazards. Climate change is casting adverse effects on food security in a wide range of ways, from disrupting the food supply chain in mountainous regions to depleting groundwater aquifers in flatter regions. Agricultural production and food supplies in Pakistan have been adversely affected by harsh weather in recent years, with an imminent threat of stress to food production in the coming years (Izraelov and Silber 2019). Climate change can have devastating effects on regions such as Pakistan that are already vulnerable and one of the malnourished regions of the world. A study over an arid region of Pakistan concluded that a rise in temperature will result in increased poverty among the farming community of the region due to dry arid land conditions (Ullah 2017).

5.2.2 Decreasing Crop Yields

The crop yields in Pakistan are expected to decline as a result of climate change, affecting livelihoods and food production. When reduced yields are combined with the country's present rapid population expansion and urbanisation, the risk of hunger and food insecurity remains significant. According to Khan and coauthors (Khan and Shah 2011), the number of undernourished people in Pakistan is approximately 27 million, amounting to 19% of the whole population. The fraction is already on the higher side and is likely to increase further owing to increasing food insecurity concerns amid climate change impacts and allied devastating factors.

Crops planted in both irrigated and nonirrigated locations are extremely sensitive to the amount of water available and temperature fluctuations. Agricultural productivity is expected to decline by 8–10% by 2040 when temperatures rise (+0.50–2 °C). Using the crop–growth simulation model, different simulation studies in Pakistan indicated a decline in major crop yields, particularly wheat and rice, as well as the length of the growing season in four agroclimatic zones. In comparison to southern Pakistan, the model indicated that a 10 °C increase in temperature would shorten the growth season of wheat in the northern mountainous region by approximately 14 days (Chaudhry 2017).

In all agroclimatic zones, less northern parts, where wheat yields are expected to grow by approximately 50% by 2080, the same study indicated a 6% decline in wheat yield and a 15–18% decrease in fine-grained fragrant basmati rice output. Various agronomic and socioeconomic factors, such as water availability, pesticides, labor supply, household characteristics, especially the number of women and previous experiences, and exposure to extreme events and seasonal weather, are found to have a substantial impact on wheat output. Summer (Kharif) rainfall is especially significant for crop productivity and yield in the winter (Rabi).

5.2.3 Effects of Increased Rainfall Variability

The increased frequency of extreme precipitation events has given rise to flash floods in the mountainous regions of Pakistan, where there is a large-scale plantation of food trees. These extreme events occurring in high-altitude mountainous areas cause flash floods over very short time intervals, thus requiring robust and resourceful monitoring and remediation. On the other hand, monitoring (as well as handling) such abruptly occurring disasters is very difficult for financially stressed countries such as Pakistan. Other than infrastructure losses, flash floods not only disrupt accessibility and power supply but also the food supply chain to and from disaster-struck regions, leading to sudden famines. A similar destructive role is played by wind and hailstorms, especially in mountainous regions. With a never-stopping population growth of Pakistan in mind, a breakage in food supply can cast huge impacts on sustainable daily life of masses. Food security, particularly for the poor, is becoming more difficult to maintain as a result of climate change (Mbow et al. 2019), which is further compounded by other issues such as population growth, water scarcity, and land degradation.

5.2.4 Effects on Agriculture Productivity

The plains of Pakistan, such as Punjab Province, benefit from irrigation water networks for their agriculture. In the current and future climate change scenarios, agriculture is one of the most vulnerable sectors. Climate change is expected to put major strains on this sector, including rising temperatures in arable areas, drastic variations in precipitation patterns (such as irregular and severe changes in monsoon rainfalls), severe water scarcity in arid and semiarid regions, floods, heatwaves, cold waves, and other natural disasters. Small landholders (who make up 80% of the overall farming population) are the most vulnerable to climate change impacts in agriculture-based regions (Ullah 2017). Shorter growing seasons, heat-induced stressors during important reproductive periods of key crops, and higher agricultural water demand are some of the effects of climate change on agriculture.

Agriculture is a vital economic sector that generates 21% of GDP, accounting for approximately 60% of exports and employing 45% of the total workforce. The overall cultivated area is 23.4 million hectares (Mha), accounting for 29% of the total reported area, with irrigated areas accounting for 18.63 Mha (24% of the total irrigated area), with Punjab accounting for 77%, Sindh accounting for 14%, Khyber Pakhtunkhwa accounting for 5%, and Balochistan accounting for 4%. Presently, 3.8 million hectares are currently under the Sailaba/Rod-Kohi, riverine, and Barani farming systems, collectively known as the spate irrigation farming system. The total area under spate irrigation is projected to be approximately 6.935 million hectares, distributed as follows: 4.68 million hectares in Balochistan, 0.862 million hectares in Khyber Pakhtunkhwa, 0.571 million hectares in Punjab, and 0.551 million hectares in Sindh (Chaudhry 2017).

5.2.5 Effects on Crop Production

Rabi and kharif are the two categories of crops. Rabi crops are planted in the autumn and harvested in the spring (March–April). The major rabi crop is wheat, while kharif crops are sown in summers. Wheat is the major rabi crop. Crops sown in summer are called kharif crops. In Pakistan, the kharif agricultural season lasts longer, with sugarcane being planted in February, cotton in March–May, rice in June–July, and maize in July–August. Rice wheat, maize wheat, cotton wheat, sugarcane wheat, coarse grain wheat, and other minor patterns are the generally adopted sowing combinations.

Wheat and rice are staple crops in Pakistan. They have specified time windows for sowing, growing, flowering, and harvesting seasons. With the specified time windows comes, accordingly, a set of suitable temperature ranges for all the above mentioned seasons for the crops. Precipitation and temperature variations during reproduction and vegetation phases are crucial in crop production (Ahmad et al. 2021). Crop yield drastically falls if any of the crucial crop-growing stages face unexpected variations in weather patterns such as temperature and precipitation. The climate change-induced increase in temperature may decrease the maturity period of a crop to 8% and may result in a yield reduction of 6%. Specifically, wheat productivity would be reduced by 7.5% at a 1 °C rise in minimum temperature (Sajjad Ali et al. 2017)an approximately 10% reduction in rice productivity (Zhao et al. 2017) during their respective growing periods. A study over a largely agriculture-based province of Pakistan (i.e., Punjab) concluded that wheat availability per capita in the province is expected to drop in the near future due to two key factors: population growth and the negative effects of changing climatic conditions (Tariq et al. 2014).

5.3 *Droughts*

The drought conditions likely to be induced by a rise in temperatures and a decline in precipitation values are a huge concern for arid and rain-fed regions of Pakistan. The scarcity of surface irrigation water compels farmers to extract groundwater as a supplement in the absence of rainfall. With little recharge to the groundwater due to aridity, the prevailing groundwater is quickly depleting, thus making a source of drinking water scarce. The depletion of groundwater resources due to climate change poses a direct risk to food security and the sustainability of daily life in Pakistan's arid and semiarid regions.

5.4 *Other Significant Climate Change Impacts in Pakistan*

5.4.1 Temperature Trends

Temperature will have more extremes. After 1950, it was observed that the number of hot days (summers) increased and that the number of cold days (winters) decreased considerably. After the middle of the twentieth century, the heat wave frequency increased. Growing heat wave events in Karachi are a glaring example. This is clear from the shifting of the winter season from October to Dec in most parts of the country.

5.4.2 Rainfall Trends

The data available for drawing conclusions for rainfall are sketchy. Most of the areas of Pakistan do not have sufficient statistical rainfall data, thus precluding the drawing of conclusions regarding rainfall trends. Strong variation in the average rainfall (decrease or increase) has been reported in different parts of Pakistan. During the monsoon season, 70% of the stations showed an increasing rainfall trend (Shaukat Ali et al. 2020).

5.4.3 Glacier Retreat

The Hindu Kush, Karakoram, and Himalayan (HKH) Glaciers mostly feed Pakistan's river systems. As a consequence of climate change, the water resources are likely to be affected due to glacial melt in the Himalayas, resulting in increased flooding within the next two to three decades (Nie et al. 2021). Thus, in the near future, the recession will in turn lead to decreased river flows. In addition, glacial recessions are also liable to the formation of moraines or ice 'dams'. Glacial Lake Outburst Floods (GLOFs) are a looming threat that can occur at any time due to breach in such moraines, with Attaabad Lake being a recent example.

Enhanced glacial melt from the Himalayan ranges has already been attributed to rising global temperatures, causing the Indus River Basin's rivers and tributaries to swell, thus inundating huge portions of the country every year since 2010. Glacial deposits provide more than 70% of river flows in Pakistan; however, glacial recession is predicted to reduce river flows during the next two to three decades (Iqbal 2013).

5.5 *Health Impacts*

- Climate change threatens humanity in many aspects. The lives of the people, food security, the health of society and thus the complete lifestyle are dependent upon climate change. There are clear indicators in Pakistan that climate change is a reality. In the Asian region, we witnessed the most weather- and climate-related disasters in the world between 2000 and 2008, and it makes approximately 29% of the world's total economic losses. Flooding has caused the greatest risk to the lives of people in addition to rising sea level, which is a constant threat to people. Severe floods in Pakistan and India in the first decade of the twenty-first century have been attributed to both climatic and nonclimatic factors. Thus, there is a likelihood of interaction between climate change and other stressors. Flooding causes epidemics and deaths and forces a large population to leave their homeland. Additionally, flooding causes water contamination. Due to the drinking of contaminated water, the masses around Pakistan have been exposed to water-borne diseases. Moreover, due to humid conditions, pathogens multiply faster, thus causing disease factors to multiply faster. Dengue in Pakistan has been associated with temperature and rainfall. Malaria prevalence has been linked to rainfall patterns. Diarrhea and Cholera outbreaks, especially in coastal regions of Pakistan, have been linked with climate change (increasing temperatures).

- In Pakistan, people have suffered from heat stress. The rate of child mortality has risen, especially in urban areas. These diseases lead to psychological stress and mental disorders. Stress syndrome has also been observed in areas where disasters struck due to climate change. Thus, climate change negatively impacts the lives of people in the country. In one of the studies carried out in our neighboring country, we explored the probability of mortality during heat waves in India. The probability of a significant increase in heat-related mortality owing to climate change impacts leading to global warming and a subsequent increase in extreme temperature and heat wave events was reported. The frequency of such events is likely to rise, making populations across India vulnerable to these extreme temperatures. The findings further warned an upsurge in heat-related mortality even with a moderate increase in mean temperatures (Mazdiyasni et al. 2017).

5.6 Miscellaneous Effects

- Animal species have migrated from one place to another due to climatic change. The species shift to an area that is better suited for their growth. Even marine species have shifted from one place to the other due to climatic change, thus shifting the abundance of a certain animal/fish to its scarcity at that place.
- Earlier greening has been observed in some forests of the Himalayas and Hindu-Kush. Wildfires may increase on the Tibetan Plateau due to permafrost degradation. The wildlife of these regions is also threatened due to changing patterns of the climate and associated effects. Coral reefs bleach with higher sea temperatures.
- Climate change would worsen existing socioeconomic inequities in resource usage and exacerbate social elements that lead to instability, wars, population displacement, and changes in migration patterns (Kitchi 2017).

- Nearly 23% of the country's territory and nearly half of the population are exposed to the effects of sudden-onset climate catastrophes, such as rising sea levels, glacial retreat, rising average temperatures, and increased drought frequency (Brief 2016)

6 Climate Action

It is clear from this research study that as a result of inaction, global warming will cause long-term changes to our climate system, with potentially irreversible repercussions. Therefore, in line with SDG 13, climate action, the following policy decisions in the context of Pakistan are suggested:

- Enhancing awareness regarding climate change at all levels, especially policy makers, will make them cognizant of visible looming threats due to adverse climate change impacts.
- Develop organizational and institutional initiatives at all levels.
- Multisectoral collaboration to address the issues of water scarcity, rising temperatures coupled with lower rainfall, lower agricultural productivity and food security.
- Introduction of drought tolerant crops, optimized water utilization for agriculture, change in cropping patterns to adapt to and mitigate climate induced agriculture vulnerabilities.
- Research studies to investigate the latest technologies and best practices to adapt to and mitigate growing climate change impact looming over Pakistan
- Ascertaining short to medium measures for climate change adaptation and mitigation at provincial and district levels.
- Integration of disaster risk reduction and climate change adaptation in Pakistan must be implemented in developmental projects and programs after pilot verification by relevant experts at all levels.
- There should be a solid communication and collaborative network of policy makers to handle such cases of risk management at all levels.
- The existing disaster risk reduction and climate change adaptation policies and plans should be re-examined to incorporate synergies and accordingly tailored depending on feedback solicited annually or quarterly from the district/local level to national-level stakeholders related to changing patterns of climate risk.

7 Conclusions

The research and knowledge on the rapidly changing subject of climate change is very vast and broad and has multifaceted dimensions focusing on both natural and manmade aspects. The recent developments in the politics of climate change and glaring onset of climate-related disasters all over the globe necessitate substantial changes to both the content and tone of the response this issue is being dealt with. The exigencies of the challenges of climate change are comparatively far more noticeable, as they were first recorded in the scientific landscape. We might have passed one or more "tipping points", as it is becoming evident from the new observations that climate change and its effects are happening at a much faster pace than projected on multiple fronts, resulting in irreversible ramifications. Climate change has direct impacts on the food, water and energy nexus, which leads vulnerable countries into a vicious cycle. Although this is now well researched and documented, a concise and accurate summary of the evidence and its implications for individual and joint action is still lacking. The climate change impacts are more pronounced in South Asia, especially in developing countries such as Pakistan, where the effects are exaggerated owing to a lack of awareness, resources, and preparedness. To face the impounding threats of climate change, more prominent indicators need the attention of Pakistan's policy makers, as recommended above. An agro-based economy renders Pakistan vulnerable to multifaceted challenges despite being in the lowest tier of GHG emitters globally. As highlighted in this study, in addition to an increase in extreme temperatures, an increased frequency of extreme weather occurrences, such as floods and droughts, is a major threat to food security, necessitating immediate attention. Since climate change impacts are directly and indirectly related to food security, the country is likely to suffer multifarious impacts in this context, leading from food shortages to decreased agriculture and crop productivity and water scarcity. It requires a multidisciplinary approach to tackle this issue with multisectoral collaboration to handle the food security issues of the country; otherwise, God forbid, the country might fall prey to a viscous cycle of famine, food security and water scarcity. Time to act is NOW.

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