Olubukola Oluranti Babalola
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Food Security and Safety Volume 2

African Perspectives

Springer

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Volume II of the book Food Security and Safety: African Perspective is dedicated to everyone working on combating the challenges of food and nutritional security, hunger, and malnutrition, and the impact of climate change in Africa.

Foreword

Africa has benefited from a wide range of innovative technologies and initiatives from both domestic and external development assistance in recent decades, all aimed at improving the continent's chances of feeding itself. Even though significant progress has been made in some areas, the reality remains that many Africans are still vulnerable to hunger. Food insecurity has become a heated topic of debate, which is affecting agricultural production. Despite its abundant human and natural resources, Africa remains food insecure. Africa can only be food secure if its citizens have constant access to safe, nutritious, and sufficient food to suit their daily dietary needs and food choices to live an active and healthy life. African governments and policy makers must take a holistic approach to achieve food security on the continent.

Academics, researchers, students, and professionals in the food and agro-industries in Africa and beyond will find this book helpful. It is impossible to overstate the importance of food security and safety in our daily lives. The book is divided into four parts: Part I focuses on food safety and human health management, which forms the bulk of the book; Part II discusses food security and nutrition issues; Part III focuses on climate change and sustainable food production; and Part IV is about animal production for improved food security.

Part I: Food Safety and Human Health

Chapter 1 investigates the potential of resistant starch type 1 for nutritional food security. It discusses the usefulness of resistant type 1 as a valuable food with health benefits in treating diabetes and obesity and suggests methods for protecting resistant starch during processing to improve functional food and nutrition security.

Chapter 2 discusses the accumulation of heavy metals in fish from rice farm channels of Pouss, Cameroon. The study evaluates the safety of fish species consumed in the region for the safety and health of the consumers. The study reported heavy metals, such as lead, constitute a health risk to consumers in the area and proffer solutions to the menace of heavy metal pollution in food.

Chapter 3 describes the evaluation of heavy metals in different food crops in the Niger-Delta region of Nigeria. Tuberous crops had high pollution concentration factor (PCF) indices for manganese, nickel, and lead, whereas maize was the only crop with the highest PCF index for zinc across all the farmlands. The study suggested that food regulatory bodies should regularly monitor the concentrations of metals and other pollutants to ensure food safety.

Chapter 4 examines the role of food in the health management of geriatrics. It discusses how diets can be used to prevent and manage diseases, such as diabetes, hypertension, cancer, Alzheimer, osteoporosis, arthritis, and cardiovascular diseases. The review considers the significance of excellent nutrition in controlling these diseases in the elderly population.

Chapter 5 focuses on perspectives and safety concerns of genetically modified crops in Africa and measures to address the problems.

Chapter 6 discusses the importance of indigenous leafy vegetables in health management in Nigeria. Most of the vegetables studied were of medicinal use with various health benefits ranging from respiratory to reproductive, digestive, and wound healing. The fact that these native leafy vegetables are a potential source of natural phenolic antioxidants that can be used as functional foods to prevent and manage many health concerns, including neurological illnesses, is highlighted in the review.

Chapter 7 highlights the application of subsurface drainage and fertilization method in reducing the toxicities of iron and sulfide in rice fields in Burkina Faso. The authors offer a strategy for combining subsurface drainage, fertilization mode, and rice variety selection in reducing iron and sulfide toxicities. These treatments also enabled rice plant growth to be optimized and productivity to be increased.

Chapter 8 describes the lessons from household surveys on plants used for managing anemia in Kenya. The study emphasizes the use of medicinal plants and other novel food ingredients in the treatment of anemia. It is evident from the study that food crops can be used as medicine.

Chapter 9 describes the potential benefits of plantain bioactive, underutilized food resources. The study reported the rich composition of plantain (phenolics, β-carotene, hydroxycinnamic acid) that can used as health benefits. A holistic view of plantains as functional foods, based on their numerous bioactive components and intrinsic nutraceutical characteristics, could lead to greater global production. The chapter highlights the bioactive components and beneficial compounds in plantain pulp and peel.

Part II: Food Security and Nutrition

Chapter 10 gives an overview of the various uses of African leafy vegetables. Because of the high nutrient density of these vegetables, they have been identified as a major source of micro and macronutrients in many households. The chapter explores the various ways the leaves can be used in vegetable soup preparations and in the development of a new class of the food.

Chapter 11 discusses the uptake of farming technological innovations for food security in the North West region of Cameroon. According to the findings in this chapter, food production is ensured throughout the year, thanks to the adoption of farming technological improvements in the research area. Food security is a fundamental human right that all people, regardless of age, are guaranteed by continuous food production. The study showed that the acquired data demonstrated that traditional farming techniques used by the Kejom Ketinguh harmed food production. Thus, the author advocates the adoption of farming technological advancements. This is because the practices led to the destruction rather than the restoration of soil nutrients.

Chapter 12 focuses on the primary drivers of food and nutrition insecurity in Africa and the strategies to improve the current food scenario. The study identifies drought, flood, and insecurity as the primary drivers of food insecurity in Western, Central, and Southern Africa. Sustainable strategies such as investing in the agricultural system through sustainable policies, lowering food prices, preventing localized desert locust outbreaks from becoming a plague, counter insurgency, climate management, and investing in food assistance in severe circumstances would all play a key role in alleviating Africa's food and nutrition insecurity.

Chapter 13 focuses on the untapped potential for enhancing food and nutrition securities using marker-assisted selection. In the face of increasingly puzzling production conditions, existing crop breeding procedures and contemporary technology could resourcefully promote crop improvement. The chapter analyzed the screening methods and patterns of how the genetic diversity of crops on the continent can be used to ensure food security.

Chapter 14 harnessed the opportunities in small-scale rural farming towards attaining food security in Southern Africa. The authors advocate the use of technology that can facilitate the challenges faced by small-scale agriculture in the region. Furthermore, the importance of scientific communication concerning small-scale farming was proposed along with practical and policy implications for enhancing and supporting small-scale agriculture for food security.

Chapters 15 discusses the use of climate-smart crops in ensuring food security as a case study from Botswana and Namibia. The emphasis is on the distinct chemical and therapeutic characteristics of climate-smart crops and how indigenous communities have employed them to ensure food security. Within the broad goal of promoting these climate-smart emerging crops toward food security, the study advocates the development of an operational policy framework and strategy for domestication and cultivation of these species. This will lead to adequate research and development on domestication, cultivation, and value chains to improve and promote these species' production, value addition, and marketing.

Chapter 16 highlights the essentials of nutraceuticals and probiotics in combating malnutrition and their therapeutic properties. The chapter discusses the health benefits, including improving immunological and respiratory functions and their effect in alleviating infectious diseases.

Chapter 17 presents the phenotypic characterization of different accessions of *Abelmoschus esculentus*. The study reported the accessions of okra with promising traits for further improvement in okra breeding and okra germplasm conservation.

Chapter 18 presents the restorative farming effects on soil biological properties for carbon stock in the northern guinea savanna of Nigeria. Malnutrition in Africa is linked to soil quality and crop productivity. Soil quality deteriorates as a result of intensive agriculture. The study conducted field trials of two cropping systems (maize and maize-legume system) with different fertilization regimes to determine the restorative effect on soil. The study recommends the use of organic amendment for the restoration of degraded soil.

Part III: Climate Change and Sustainable Food Production

Chapter 19 describes the impact of climate change on food security and the adoption of strategies for sustainability among households in Nigeria. Finally, the chapter reported the consequences of climate change on food security and health management and food security adaptation techniques for health management.

Chapter 20 analyzes the granger casualty and ARDL modeling approach for climate change, growth in agriculture value added food availability, and economic growth in the Gambia. This study used annual data from 1960 to 2017 and evaluated it using the ARDL technique and the Granger causality theory to predict growth and livestock production and its impact on the country's GDP. It was evident from the study that the expansion of food imports and agriculture has a detrimental impact on GDP growth. The study established the importance of fish and animal production, climatic change, and crop production in controlling food availability and economic growth in the Gambia.

Part IV: Animal Production for Improved Food Security

Chapter 21 calls for a paradigm shift in goat production from the traditional way to the adoption of genomics and other breeding strategies. Goats contribute significantly to poverty reduction, rural economic development, and increased nutrition. Indigenous goats have a significant genetic diversity that allows them to adapt to changing settings and provide food security. Molecular genomics has opened up new frontiers for animal development by speeding up genetic advancement, increasing the accuracy of superior trait selection, and mapping economically essential genes. The genetic advantage can be increased by incorporating genomics and screening for many specific mutations or genomic variants that underpin critical features.

Lastly, we would like to express our gratitude to all the contributors for agreeing to be a part of this book, as well as all reviewers for graciously taking the time to read the numerous manuscripts submitted for the book and providing their insightful comments and suggestions.

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Preface

This book focuses on food security and safety issues with an emphasis on Africa. The continent is currently faced with food insecurity issues and is most affected by undernourishment. The continuous increase in the human population in Africa will lead to more food demands. For Africa to be food secure, safe, and nutritious, food has to be available, well distributed, and be sufficient to meet people's food requirements. Achieving this requires that collective action be taken for the problems to be resolved to achieve food security and nutrition in Africa.

Food Security and Safety: African Perspectives Volume II identifies those factors that lead to food insecurity in sub-Saharan Africa and highlights the positive efforts being made to address them through an interdisciplinary approach. It enhances the knowledge base of food security, food safety, and food production, which have been major scientific and political topics of discussion in recent times, and also identifies the possible constraints to food security and addresses how these constraints could be overcome. Climate change has affected food production in most parts of Africa because of drought and excessive temperatures, reducing crop yields and loss of livestock and income. The need to focus on climate-smart crops for sustainable agriculture was highlighted in some chapters.

This book is intended for researchers, academics, and students involved in scientific research and innovation in food security, food safety, and food production, and food safety professionals involved in the food industries. It will also be helpful for policy makers and government agencies in Africa involved in ensuring food security and safety in the various African countries. Topics covered in the book chapters include the role of neglected and underutilized crops in enhancing food security and reducing malnutrition in Africa, food security issues in Africa, the impact of climate change on food security, technological advancements using modern technologies, such as biotechnology and nanotechnology, to enhance food quality, and food safety issues.

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About the Book

This book focuses on the safety and security of food, human health management, and the impact of climate change on sustainable food production in Africa. The progress, prospects, and problems of sustainable food production and consumption in Africa are covered in this book series, which aids global efforts toward sustainability.

The book promotes studies in cross-disciplinary academic subjects, such as sustainable agriculture systems and practices, restoration of degraded land, food nutrition, and conservation agriculture as well as climate change impact issues. It also concentrates on genetically modified crops, uptake of farming technologies, various aspects of food security, as well as nutrition, and the reduction of hunger and malnutrition. This volume addresses the ideas and practices of food security as a whole, providing an overview or a wide analysis of the subject's many sub-disciplines. This series covers all aspects of food security, including production, stability, the economics of food production, climate impact, and nutritional value of food.

The goal of this series is to provide a comprehensive review of the most recent research efforts by writers on Africa's food security difficulties, small-scale farming, as well as the continent's economic and social challenges. It is made up of single chapters written by a variety of scholars, and each chapter is self-contained, although they are all linked by a similar research theme. We hope this volume will open up new study avenues for future breakthroughs.

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About the Editors

Olubukola Oluranti Babalola Pr.Sci.Nat., MASSAF, FASLP, FTWAS, FAS, Vice President of OWSD, is an NRF-rated scientist with over 20 years of research experience focusing on rhizosphere metagenomics, coupled with an MBA in general management. She has consistently advocated using biofertilizers over and above chemical fertilizers for plant health management. Her effort for SDG 2 "Zero Hunger" in the continent of Africa for food security and sustainable agriculture is helping farmers, women, and all food lovers. She is the incumbent research director of the Food Security & Safety Focus Area at NWU. Her laboratory attracts students from across the world. Olubukola is a member of the editorial boards of *Applied and Environmental Microbiology* (American Society for Microbiology, USA), *BMC Microbiology* (Elsevier), and *Biochemistry & Biophysics Reports* (Elsevier). She has received many awards, including being the finalist, GenderInSite 2020. She is passionate about capacity building and has graduated 29 doctoral fellows, 24 master's, and numerous honors students. Olubukola is a prolific author with about 300 publications. Her Springer edited book is entitled *Food Security and Safety: African Perspective*. She is an AAAS-TWAS Science diplomacy alumnus, impacting the world after the eye-opening awareness of policy making, diplomacy, and diplomatic engagement. She is now taking action using the gender lens and forging collaborations with diplomats. She is a fellow of The World Academy of Sciences (TWAS), the Academy of Science of South Africa (ASSAF), and the Nigerian Academy of Science (NAS). Her wealth of international experience spans the universe. She enjoys international collaborations, research grants, and many awards.

Ayansina Segun Ayangbenro is a postdoctoral fellow at North-West University, South Africa. He obtained his bachelor's and master's degrees from the Federal University of Agriculture, Abeokuta, Nigeria, and his PhD from North-West University, South Africa. He is a recipient of NRF/TWAS Doctoral Scholarship Award. His research interests include ecology of soil microorganisms and recycling of nutrients, and plant-microbe interactions. Ayansina has authored and co-authored many peer-reviewed journal articles published in reputable national and international journals. He is a member of the South African Council for Natural Scientific Professions.

Omena Bernard Ojuederie is a seasoned researcher and academic with expertise in plant genetics and biotechnology. He was a postdoctoral research fellow in the food security and safety niche area at North-West University, South Africa. His research focuses on biodiversity assessment and phylogenetic studies of underutilized crops, plant tissue culture, molecular biology, plant-microbe interactions, and improving food security in Africa. He is a member of the editorial board of the *Journal of Underutilized Legumes* and a grantee of the International Foundation for Science (IFS), Sweden. He is currently an extraordinary senior lecturer in the food security and safety focus area, North-West University, South Africa, and a senior lecturer in the biotechnology unit of the Department of Biological Sciences, Kings University, Nigeria, where he also serves as the acting director of research and linkages and acting director of academic planning and quality assurance.

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List of Abbreviations

AAS	Atomic Absorption Spectrometry
AKST	Agricultural Knowledge, Science and Technology
CVD	Cardiovascular Disease
EDI	Estimate Daily Intake
FAO	Food and Agriculture Organization
FONADER	Fond National de Développement Rurale
GM	Genetically Modified
GTZ	German Technical Assistance
GWAS	Genome Wide Association Studies
HOF	Horn of Africa
IKS	Indigenous Knowledge System
IPC	Integrated Food Security Phase Classification
IRAD	Institute for Research and Development
IRB	Iron-Reducing Bacteria
IRZ	Institut de Recherche Zoologique
Km^2	Kilometer Square
MAS	Marker-Assisted Selection
MDGs	Millennium Development Goals
MIDENO	North West Development Authority
NGOs	Nongovernmental Organizations
OECD	Organization for Economic Cooperation & Development, Development
PAFSAT	Farming Systems Based on Animal Traction
POG	Pass on the Gift
RDA	Dietary Reference Intake
RDS	Rapidly Digestible Starch
RFLP	Restriction Fragment Length Polymorphism
RS1	Resistant Starch type 1
SDG	Sustainable Development Goals
SDS	Slowly Digestible Starch
SRB	Sulfate-Reducing Bacteria

SSA	Sub-Saharan Africa
TETFund	Tertiary Education Trust Fund
UNEP	United Nations Environmental Programme
UNO	United Nations Organization
USSR	Union of Soviet Socialist Republic
WADA	Wum Area Development Authority
WHO	World Health Organization
WHO	World Health Organization
XRF	X-Ray Fluorescence

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Part I
Food Safety and Human Health

Chapter 1
The Potential of Resistant Starch Type 1 for Nutritional Food Security

Ebun-Oluwa Peace Oladele and Aly Mbaye

1.1 Introduction

Sustainable food security involves the collaboration of many disciplines, which include but are not limited to science and technology, public health, and the social sciences. This is because the provision of adequate, healthy, and safe foods involves many stages ranging from production, transportation, storage, processing, preservation, preparation, and finally to consumption (Karunasagar and Karunasagar 2016). According to FAO (2010), food security refers to "people having physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and preferences for an active and healthy life" (FAO 2010). Why is food security usually addressed with a focus on nutritional security, food safety, and global environmental change? It is because all mentioned parameters in the definition of food security have either a direct or a potential impact on productivity and public health (FAO 2010). Unfortunately, food and nutritional security have somewhat been downplayed, especially in developing nations, particularly in Africa. This is because poverty constitutes a significant problem, and therefore more focus is placed on food production than other areas of food security. The focus of food security in many meetings and organisations had always been on agricultural yields and food volume as well as the maximisation of underutilised crops (Karunasagar and Karunasagar 2016). Little attention has been given to food value in terms of functional food security, which is a critical aspect of food security. According to FAO

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(2007), logically, food consumption becomes beneficial when it can meet dietary, nutritional, and health needs. The final nutritional quality of food consumed is largely dependent on one or all-preceding processes/factors. Therefore, it is quite critical to begin with good agricultural practices to prevent exposure to heavy metal contamination and other environmental hazards and then proceed to proper food processing and preparation (Karunasagar and Karunasagar 2016).

The issue of functional food and nutrition security needs to be addressed with dedication and urgency as a tool in tackling the looming crisis of food security in Africa and the world at large. Indeed, many areas need to be monitored in tackling the future of nutrition security. Recent and consistent weather changes witnessed in most regions of the world have caused a reduction in agricultural productivity and nutrient availability and subsequently an increase in the threat to nutritional food security (Mubaiwa et al. 2018). In these times and age, agricultural production and food handling should be targeted towards providing nutritious foods that will meet the dietary needs of the populace so that individuals can eat good and enjoyable meals within the compatibility of well-being and good health and subsequently lead an active and productive life (FAO 1998). Agricultural processes from farm to the table should be aimed at providing and preserving nutrients in food such that consumers get both food and nutrient satisfaction. An ample amount of money, effort, and resources have been expended on improving human nutrition through the biofortification of micronutrients (Bouis and Saltzman 2017). While this is a good and worthy venture, it should be noted that some macronutrients such as RS1 are constantly being destroyed (during food processing) or at best ignored in many food preparation processes.

The enhancement of human health is not generally a fundamental goal of agricultural policy, despite the apparent and sophisticated links between health, nutrition, and Agricultural Knowledge, Science and Technology (AKST). The use of modern methods for food production and processing has been enhanced by AKST strategies, guidelines, and procedures (FAO 1998). Unfortunately, a reduced quality of meals and diets is becoming increasingly common across various cultures and continents, especially in developing nations. The widespread consumption of inexpensive foods with low nutrient intensity has been associated with increasing worldwide obesity, diabetes, and other non-communicable diseases. Poor diet throughout a man's life is among the leading causes of global deaths because it is a significant determinant condition for chronic diseases. Dietary quality and consumer well-being rather than food price should be the drivers of food production (FAO 1998).

Dietary patterns in Africa in which carbohydrates form a major part of a meal had probably developed over the years due to poverty, which is hinged on the inability of many households to purchase protein-rich foods. The situation over the years has barely improved in this regard, and this might have contributed to the high incidence of diabetes and obesity in the continent. Carbohydrate foods are generally more abundant and therefore need to be utilised/consumed in such a way that maximum nutritional benefits are derived from them. This would involve addressing issues such as processing and cooking, which usually bring about destruction or non-preservation of some useful ingredients. In Africa, the consumption patterns for different carbohydrate foods vary from food to food and across various cultures and as well as from person to person. There are some food processing techniques, such as physical methods (e.g., milling), which may destroy the food matrix as well the structure of starch in the food and consequently result in a depletion of RS1 content (Mubaiwa et al. 2018). For example, Bambara groundnuts are consumed in many ways, some of which may lead to the destruction of the intrinsic structure of the seeds and subsequent loss of some of the resistant starch present. Newly picked seeds are usually consumed as snacks after grilling or boiling for about an hour (Swanevelder 1998; Azam-Ali et al. 2002). Dry seeds are, however, difficult to grind due to their tough and snugged seed coats. These seeds are first pounded (using a mortar and pestle) before grinding into flour. The flours are then used to make small flat cakes and bread (Swanevelder 1998; Linnemann 1987). Other consumption patterns for the dried seeds include initial soaking and/or boiling to make a snack or porridge (Swanevelder 1998). In addition, Bambara groundnuts can be roasted before milling to produce flour with a nice and delicious aroma, which is used to make Bambara soup or sauce. This nice-smelling flour can also serve as a substitute for coffee (Halimi et al. 2019). Food processing practices can be assessed from different viewpoints, e.g., suitability and sustainability of the method, energy consumption and cost, processing time, and the sensorial and nutritional aspects of the final product (Mubaiwa et al. 2018). Food processing improves the sensory qualities and bioavailability of nutrients from food (Jeong et al. 2019), but several studies indicate that processing may lead to depletion of some nutrients as well (Gabor 2018; Jeong et al. 2019; Brand et al. 1985).

The objective of this chapter is to draw attention to resistant starch type 1 (an important nutritional starch fraction for the management of diabetes and obesity), how it is lost during food processing, and the need to preserve it as a critical tool in addressing functional food/nutritional security. This cannot be overemphasised in the face of looming food security in developing countries and the world at large.

1.2 The Importance of Carbohydrate Nutrition for Sustenance

Carbohydrate foods such as bread, rice, cassava, and potatoes are staples for many populations of the world. For example, "Rice (*Oryza sativa* L.) is the staple food for billions of people worldwide, with global consumption estimated at 402 million metric tons (milled rice basis) and a global per capita food use of 54.1 kg per person in 2016/2017" (FAO 2017). Unfortunately, little attention is being placed on the nutritional values of many carbohydrate foods except for the provision of energy. The digestion and intestinal absorption of cooked white rice are complete or almost complete in man (Strocchi and Levitt 1991). However, it is possible to alter the rate of digestion to derive the benefits of non-digestible carbohydrates that may be present in rice. This is also applicable to many carbohydrate foods. Control of domestic processing methods, hydrothermal treatments, and dietary patterns can make significant contributions to an increase in carbohydrate nutrition, especially starch nutrition (Toutounji et al. 2019).

The function of food components in the prevention/management of chronic conditions has attracted much research interest. The abundance of carbohydrate foods everywhere on the globe should be assessed to increase the nutritional benefits derivable from them. Starch and fibre are particularly important constituents of food carbohydrates. Fibre has drawn increased attention in the last decade and with the call to increase the number of indigestible carbohydrates in food, occasioned by the surge in the cases of type 2 diabetes and obesity (Otles and Ozgoz 2014). On the other hand, starch, which is the most abundant carbohydrate in food and an ingredient with an energy value of 17 kJ/g (4 kcal/g) (Toutounji et al. 2019), appears to be an underutilised giant in terms of nutritional values derivable from foods.

Current knowledge indicates that it is not all starch that is digested in the human small intestine. Some starch fractions are not digested, while some are slowly digested. Starch has therefore been nutritionally classified depending on the rate of digestion (Englyst et al. 1992). These are given below:

Rapidly digestible starch (RDS): This is starch digested within 20 minutes of ingestion.

Slowly digestible starch (SDS): This is starch digested between 20 and 120 minutes of ingestion. It has been demonstrated to produce a moderate postprandial glycaemic and insulinemic response and is therefore valuable for the dietary management/control of hyperlipidaemia, type 2 diabetes, and related conditions (Aller et al. 2011).

Resistant starch (RS): Resistant starch is not digested in the small intestine. It behaves like dietary fibre because it provides a substrate for the microbial fermentation of short-chain fatty acids (SCFAs) in the human gastrointestinal tract (Toutounji et al. 2019).

1.2.1 Should Carbohydrates Be Eliminated from Diets?

Carbohydrates are essential nutrients in human nutrition. They consist of starch, sugars, and fibres. The major sources of calories are the sugars and soluble starch, while resistant starches and dietary fibres synergistically promote gut health and contribute significantly to the management of some non-communicable diseases such as hypercholesterolemia and type 2 diabetes (Smith et al. 2013; Tosh and Yada 2010). Today, many dietary recommendations include either the reduction or elimination of carbohydrates. Even though this may be beneficial in some instances, it would have been more appropriate to specify the carbohydrate type(s) in question. This is because the elimination of useful carbohydrate types may lead to nutritional deprivation of some useful prebiotics needed for better overall body metabolism and well-being.

Global programs and campaigns on malnutrition have often focused on improving protein quality, iron fortification, etc. An improvement in carbohydrate quality could be an index to reduce malnutrition. In addition, as would be expected, more attention has been placed on child malnutrition; however, the somewhat neglect of malnutrition in adults can have severe consequences. The concept of undernourishment can also occur in adults, and this is implicated in the high incidence of obesity and diabetes mellitus ravaging the entire world today. The attempt to reduce or even eliminate some classes of carbohydrates, e.g., starch and sugars, and consume more dietary fibres may lead to hypoglycaemia, weight loss, and related conditions. This situation can be rescued by the consumption of slowly digestible starches in some instances. For example, weight loss is an important marker of malnutrition and occurs in many patients suffering from diabetes (Nadukkandiyil et al. 2015). Weight loss, in this case, usually occurs as a result of the elimination of carbohydrate foods to avoid hyperglycaemia and glucose spikes. Foods rich in slowly digestible starches such as boiled unripe plantain (Oladele and Williamson 2016) will supply blood glucose at a slow rate and prevent glucose spikes in diabetic patients and subsequently avert or reduce weight loss in these groups. Slowly digestible starch (SDS) has been shown to be helpful in the dietary management of individuals with chronic and metabolic conditions, particularly those with type 2 diabetes and hyperlipidaemia. This is because SDS elicits a modest postprandial glycaemic and insulinemic response (Aller et al. 2011).

Carbohydrates are a large and diverse group of food components with varying and useful nutritional and therapeutic qualities, which need to be properly understood, incorporated into diets appropriately, and maximally annexed.

Type 2 diabetes and related ailments such as obesity are now occurring at endemic levels worldwide. There is, therefore, an urgent need to develop foods that will reduce or eliminate their impact. These foods include those containing high levels of slowly digestible and/or indigestible carbohydrates, which have the potential to produce a slow and steady post-meal blood glucose response (Toutounji et al. 2019).

1.3 The Importance of Resistant Starches and Why Resistant Starch Type 1 (RS1) Should Be Protected in Foods

The FAO (1998) indicates that inadequate diet during a person's lifetime is a key risk factor for chronic diseases, which are the primary cause of deaths worldwide. There should be a paradigm shift from food quantity and price to dietary and nutritional quality as the major drivers of food production. The right approach for this would include fiscal policies (taxation, trade regimes) for health-promoting foods and regulation of food product formulation, labelling, and commercial information.

The evolving epidemic of chronic non-communicable diseases can be linked to a complex range of factors, which includes changes in food consumption patterns, habitual diets, and lifestyles – together called the "nutrition transition". The increasing consumption of cheap calories from fat and sugar, combined with a more desk-bound lifestyle, mainly linked with urbanisation, has led to a sharp rise in obesity (FAO 1998). Urbanisation has also led to changes in domestic cooking practices with the use of grinders, smoothie makers, etc., on the rise. The consequence of these changing practices is that many food nutrients are gradually being eroded from daily dietary intakes, which subsequently culminates into a surge in many non-communicable diseases such as obesity and diabetes. The prevalence of obesity, type 2 diabetes, and related chronic diseases in both developing and developed countries is frightening. According to the World Health Organization (WHO), "there are now more than one billion overweight people in the world, and obesity is considered a world epidemic. Around 1.9 billion adults are either overweight or obese" (WHO 2016b), "while 382 million people suffer from type 2 diabetes worldwide" (WHO 2016a). This epidemic, therefore, requires urgent attention.

There is an urgent need to educate the populace in various communities of the need to increase physical activity and embrace a balanced diet, as well as reconsider food preparation methods to tackle these global health concerns. For diet, the accessibility of healthy food choices is essential and should involve a population-based approach that entails intervention from both food production (e.g., modification of primary produce) and food processing sectors (e.g., reformulation of food products) (Toutounji et al. 2019).

Research areas focusing on the prevention of chronic diseases using dietary components and functional food ingredients are on the rise. Resistant starch, as indicated above, is the portion of starch in foods that is not digested in the human digestive tract and is quite beneficial for gut health (Butardo and Sreenivasulu 2016).

Resistant starch has been categorised into five types (listed below). These categories indicate why starch may escape digestion and absorption in the human small intestine (Oladele 2013; Englyst and Kingman 1990; Brown et al. 1995; Jeong et al. 2019).

RS1: physically inaccessible starch, e.g., partially milled grains and seeds.
RS2: resistant starch granule, e.g., starch in raw potato and green banana.
RS3: retrograded starch, obtained in cooked and cooled foods, such as cooled potato, bread, and corn flakes.
RS4: chemically modified starch obtained from chemically cross-linked and acetylated starches.
RS5: amylose-lipid complex, i.e., the amylose-lipid complex portion in starch.

1.3.1 Resistant Starch Type 1 in Foods

Resistant starch type 1 is formed when starch is physically trapped within the food matrix after 2 hours of ingestion. Digestive enzymes are unable to access starch physically when starch is held in food pieces that have not been broken down completely (Roder et al. 2005). A crucial factor in enzyme digestibility is accessibility to the substrate (Oladele 2013). Why are some starch portions not digestible? Starch hydrolysing enzymes cannot access some of the starch in food; hence, they are indigestible. This type of resistant starch can be found in whole-grain foods, partly milled grains, seeds, and some very dense types of starchy foods, e.g., unripe plantain (Oladele and Williamson 2016); therefore, milling or grinding can release the starch to make it digestible (Sajilata et al. 2006). This, therefore, suggests that food preparation and food-processing methods could play an important role in preserving the RS1 content of food if/when it is present in the food matrix. For example, boiled unripe plantain was reported to have an RS1 value of 8.2 ± 1.9 g/100 g, whereas RS1 was not detected when the same sample was dried and grounded into powder before analysis. (Oladele and Williamson 2016; Oladele 2017). In addition, it appears that the presence of RS1 in boiled unripe plantain also resulted in a significant quantity of SDS (13.3 ± 1.9 g/100 g) being detected, whereas no SDS was detected in the grounded sample (Oladele 2017). Foods containing RS1 will have several physiological benefits and should draw great attention.

The contact between substrate and enzyme is usually increased by a larger surface-to-volume ratio, which can be achieved by a smaller granule size (Blaak et al. 2012). This subsequently results in a proportionate increase in digestibility. An understanding of the impact of processing on starch digestibility can therefore provide a valuable tool for the regulation of starch digestibility of existing food products and diets (Toutounji et al. 2019).

RS1 is structurally driven and can be manipulated with appropriate pre-processing food techniques/methods (Roman et al. 2019). Therefore, the ability to be able to produce, increase, or reduce RS1 in foods will be an important tool in food applications in order to achieve the desired nutritional and therapeutic benefits. These benefits can be explored in industrial food production as well as in domestic food preparations for home consumption.

Almost all cooking methods involve some form of heat processing, such as boiling, baking, and frying. Heat treatment improves the accessibility of starch to enzymes; however, a portion of the starch (called resistant starch) in food may remain resistant to α-amylase hydrolysis in the small intestine. Of the five types of resistant starch, RS3 is the most common resistant starch fraction in heat-treated foods; however, this is peculiar to cooked and cooled foods only. In addition, the formation of RS3 involves retrogradation, which is somewhat a complex process. When starch is heated, the granule is completely hydrated, and amylose is leached from the granules into solution as a random coil polymer. Amylose chains start to re-associate as double helices, stabilised by hydrogen bonds when starch is cooled. Upon further retrogradation, the double helices pack in a hexagonal unit cell. The close packing of amylose double helices leads to the formation of crystals (Haralampu 2000; Wu and Sarko 1978), which prevents the accessibility of digestive enzymes. "RS3 may not be the most common type of resistant starch type in foods. Freshly cooked foods in most cases do not usually contain RS3 but may contain reasonably high quantities of RS1, depending on the food matrix" (Oladele 2017). Many studies to quantify resistant starches in foods have dealt only with total resistant starch. Furthermore, many of the studies carried out to measure resistant starch have been performed using starches and flours, and the consequences are those intact food matrices that would have aided the formation of RS1 in the cooked foods would have been disrupted by milling (Oladele 2013). There is a need to carry out elaborate studies on many food types to determine the quantity of RS1 present in such foods. This will lead to the exploration of how it can be improved for food security and sustainability purposes.

People in various continents and regions of the world have been processing their food in one way or the other, such as cutting, cooking, or grinding, for hundreds and thousands of years. Domestic cooking methods also include but are not limited to grilling, frying, and steaming. Food processing methods and techniques are not the same and do not affect food micro- and macronutrients the same way. It is, therefore, possible that changes in food processing over the last few hundred years have got a lot to do with the epidemic of metabolic diseases that the world now faces (Gabor 2018).

Culturally acceptable food processing techniques have been the bane of nutrition security concerning RS1. There is a need to improve cooking and consumption methods to optimise nutrient bio-accessibility. When RS1 is quantified using starches and flours instead of whole foods, then RS1 (which is the physically inaccessible starch) present in foods with a dense or rigid structure may be omitted. This is because milling/grinding would have disrupted undamaged food matrices that would have aided the identification of RS1 in some cooked foods (Oladele 2017).

Grinding of grains is an age-long food processing technique that changes the hormonal response in the small intestine. According to a study by O'Dea et al. (1980), when healthy individuals ate grain-based meals, the plasma insulin response was dependent on the particle size of the grains, i.e., insulin released increased from whole grain to cracked grains to coarse flour for the same amount and type of food. Fine flour of the same quantity in the same food activates the highest insulin response (Gabor 2018). This phenomenon has also been observed for rice types. Interestingly, for rice samples, this ideology became more apparent as there was not a big difference in the insulin response between brown rice and white rice of the same quantities. In addition, it was observed that the difference was not due to the amount of fibre, as it did not make a difference when the fibre was added back to a sample. The extent of grain structure disruption was the observed reason for the differences in insulin response for the various samples. Therefore, the concept of consuming whole wheat bread as opposed to white bread may not produce significant differences in terms of insulin response because it just involves consumption of fibre that was ab initio taken out (Gabor 2018).

Roman et al. (2019) presented a successful strategy to slow down the rate of digestion of fully gelatinised starch in baked food products by manipulating the extent of grinding as well as the starch molecular structure. In that study, more slowly digestible starch (SDS) was generated by adding banana pulp to breadcrumbs. Banana, which is part of the Musa species, is one of the food products rich in RS2 and can generate large quantities of RS1 and RS3.

Another useful and abundant food product that may be explored for the generation of RS1 is corn. The consumption of whole grains has been reported to be usually inversely associated with BMI, while consumption of refined grain is not (Gaesser 2007). Corn can be processed in different ways, such as wet milling, dry milling, dry-grind ethanol processing, and alkaline processing. Each of these processes has specific measurement techniques that help select the optimal quality of corn for the desired purpose (Paulsen 2008). Corn has been one of the few reported sources of RS1. However, RS1 is only present in partly milled corn; hence, the ability to manipulate production processes that will reduce grinding for different corn products will culminate into an RS1-rich product.

SDS- and RS1-rich foods can be consumed as whole foods, used as food substitutes for home consumption or even as substitutes after maximising the nutritional benefits in industrial food production. The abundance of starch-rich foods can be used to resolve the problem of food security, particularly functional food security. This is possible through the manipulation of processing methods to generate more resistant and slowly digestible starches, which would improve carbohydrate quality and overall health and well-being.

The subject of carbohydrate quality and quantity has been receiving immense attention in recent times. Several reports propose that diets with a high glycaemic index or glycaemic load, or that are high in refined carbohydrates increase the risk of obesity and associated health problems (Argiana et al. 2015; Stagi et al. 2015; Oladele and Williamson 2016; Zafar et al. 2019a, b). Of course, this is true, but the inability to strike a balance in the campaign for the consumption of "healthy" versus "unhealthy" carbohydrates is a major problem that needs to be addressed quickly because the campaign for low-carbohydrate diets has underscored the disparity that exists between carbohydrate types. More recommendations are now being given for increased consumption of complex, fibre-rich carbohydrates with a low glycaemic index such as oats, unripe plantain, and pulses, and reduced intake of refined and high glycaemic carbohydrates like white bread, refined sugar, and biscuits and cakes. Despite the numerous documentation justifying the consumption of fibre-rich carbohydrates, there is very scarce information promoting the consumption of resistant starches. Even when such exists, very few make mention of the need to identify and classify resistant starches present in foods. The recognition of the huge benefits derivable from RS1 in terms of food functions and flexibility of incorporation into food products has, unfortunately, been ignored. Improved knowledge of the impact of processing on starch digestibility can offer a promising and effective means for food manufacturers to regulate the starch digestibility of existing food varieties (Toutounji et al. 2019).

1.3.2 Climate Change, Food Security and Resistant Starch Type 1

Food security has three major components (Fig. 1.1): food utilisation, food access, and food availability. “Food system processes, such as food processing, distribution, acquisition, preparation, and consumption, are as important for food security as food and agricultural production are” (FAO 2008). Therefore, resistant starch type 1 constitutes an important part of food/nutritional security because it is very much affected by food processing.

Food utilisation is the use of food and the ability to derive essential nutrients from food when consumed. This includes diet composition, nutritional values, and preparation methods. Climatic conditions can affect dietary patterns both negatively and positively, producing changes in dietary patterns. This results in novel challenges for food safety, and this may affect nutritional status in various ways (FAO 2008).

It appears as though technological advances in the transportation of agricultural products and finished goods throughout the world have brought remarkable improvement in the entire food system performance, and subsequently less dependent on climatic conditions than it was 200 years ago (FAO 2008). However, it should be borne in mind that the movement and delivery of packaged foods are still very much dependent on weather conditions at both originating and finishing points (Ellis and Sunberg 1998). In addition, the nutritional values of fresh and packaged foods of the same products may differ significantly (FAO 2008). Climate changes affect crop yield and subsequently food consumption and preservation practices which ultimately culminate into varied nutritional benefits derivable from such foods.

Climatic conditions do affect food preparatory methods and food consumption patterns, especially in Africa. For example, plantain is one of the most important sources of resistant starch (and RS1 in particular). Plantain production and

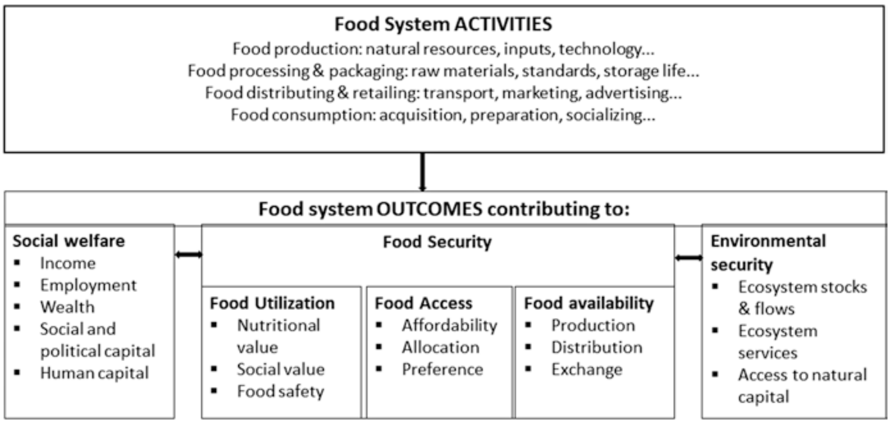

Fig. 1.1 Food system activities and food security outcomes. (Adapted from FAO 2008)

consumption patterns are very much dependent on weather conditions (Kainga and Seiyabo 2012).

During the year when it is abundant, many homes prefer to have it boiled or roasted, and these are the forms with a greater quantity of resistant starch (Oladele 2013; Oladele and Williamson 2016). At other times in the year, many homes rely on the dried and ground forms, which are usually made into a stiff porridge form called amala (in the Western part of Nigeria), which has a lower resistant starch content. Therefore, variations in climatic conditions will affect food processing, consumption patterns, and subsequently resistant starch content of foods. Changing climatic conditions will affect food production and preservation patterns in the food system. For example, in the case of plantains, a need to preserve food in the dried form by grinding it into powder will be promoted to protect against hunger, whereas "hidden hunger" in the form of nutrient depletion will occur due to this practice. This is because RS1 will be destroyed as against when the plantain is consumed in the fresh form, as discussed in Sect. 1.3.1 above.

Changes in weather conditions in countries that are major producers of plantain and other food crops that have great potential for generating resistant starch will result in changes in cultural practices, consumption patterns and disruption in nutritional food supply and subsequently nutritional food security. Climatic factors, e.g., rain, soil, temperature, sunlight, etc., can affect the growth and yield of many crops, especially wild foods such as plantains. Many homes that strive to produce food or guarantee a means of livelihood rely on wild foods largely; therefore, these climatic factors could also have an impact on food availability (Porter and Semenov 2005).

Food production and distribution are already being affected by both normal and more serious extraordinary climate conditions such as rainy seasons, dry seasons, warm and cold waves, overwhelming storms, and floods. This has also translated to the incidence of food emergencies and severe impact on human health and livelihoods in both urban and rural areas (FAO 2008). Climate change will also result in the emergence of new forms of pests and diseases, affecting plants, animals, and humans and presenting unknown risks for food security, food safety, and human health (FAO 2008).

In general, however, the impacts of climate change on nutritional value (as part of food utilisation) is likely to be felt indirectly. The physiological utilisation of foods consumed, which involves people's capacity to obtain necessary nutrients, affects nutritional status (FAO 2008), and nutrition and nutritional status are key factors regarding the upsurge of non-communicable diseases around the globe today.

The strength of resistant starch type 1 in the face of looming food/nutritional security due to climate change is that modifications to cultural practices/food preparation methods of existing staple foods could result in better physiological utilisation of foods for increased derivable nutrients and reduced risk of diabetes, obesity, and related conditions.

1.3.3 The Economic Implications of Having RS1 Foods

Grinding, milling, and particle size reduction are domestic and industrial processes that involve the use of energy. Literally, it is cheaper to consume some foods in their whole form without cutting or grinding. A good example is plantain, already reported to have good levels of RS1 as well as a low glycaemic index (Oladele and Williamson 2016). Consumption of unripe boiled plantain only requires cutting and boiling process, whereas consumption of plantain flour meal (referred to as elubo in the western part of Nigeria) requires cutting of the plantain finger into slices for easy drying, grinding into flour, and then cooking. It is obvious that the plantain flour meal will consume more energy, more time, and economically more expensive. Ironically, fewer benefits are derived from the plantain flour meal than boiling the whole plantain finger and consuming it without grinding, a form that has been proved to have therapeutic properties (Oladele and Williamson 2016; Oladele 2017). It can therefore be logically concluded that the preservation of RS1 in RS1-rich foods is actually an economically wise decision. Why go through the grinding/milling process only to destroy the nutritional quality of food.

Another example is rapeseed; in the fractionation of rapeseed meal, air classification, a fractionation technique was used to obtain rapeseed meal fractions of differing contents of crude protein, fibre, and lipids. Jet milling and air classification are, however, techniques that require a high input of energy during milling and classification. A higher crude protein fraction yield can be achieved by ball milling, subsequently followed by sieving. This procedure also results in a better up-concentration and removal of fibre compared to air classification. This process also consumes less energy; however, ball milling results in greater loss of RS1 as the sample matrix is disrupted more (Hansen et al. 2017).

What should be advocated for to effectively tackle functional food security is to reduce or even eliminate domestic and industrial processes that disrupt the food matrix and increase digestibly to the detriment of resistant starch present in the food. Whole grains should be consumed as they are, without any initial grinding steps. Therefore cornmeal/flours produced by grinding grains, cereals etc., should be reduced or discontinued except for infant or weaning foods. The outcome is hypothesised to be a reduction in the incidence of obesity, diabetes as well as the overall cost of food production and consumption.

1.4 Conclusion

Food availability will be a fruitless effort if health benefits are not preserved. Evaluation of nutrient bio-accessibility and product functionality is necessary for appraising the quality of food products. Starch digestibility studies are foremost now, as nutrient deficiency is still a challenge that besets sub-Saharan African communities despite the abundance of many and varied agricultural food products.

RS1 is a viable food option in nutrition security, as climate change issues, covid-19, etc. do not necessarily affect it. Investigations into more food sources to generate a database for RS1 containing foods is critical at this time. Studies on the food processing and nutritional aspects of resistant starches (and in particular resistant starch type 1) are recommended. Ultimately, knowledge sharing and education within communities will go a long way to help improve domestic cooking practices.

Non-governmental organisations are urged to carry out awareness and sensitisation workshops for improved processing techniques and better consumption patterns for already existing food crops with great potential to generate resistant starch type 1.

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Chapter 2
Evaluation of Bioaccumulation of Heavy Metals in Some Fish Species from the Far North, Cameroon Rice Farms' Channels of Pouss

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2.1 Introduction

Contamination of aquatic ecosystems general and particularly of fish by heavy metals is seen as a serious environmental and sanitarian issue worldwide. This is owing to their toxicity, persistence, and accumulation (bioaccumulation and biomagnification) in the food chain and their effects on health of populations (Asuquo et al. 1999, 2004; Papagiannis et al. 2004; Alhas et al. 2009; Dhaneesh et al. 2012; Ekengele et al. 2015; Gbogbo et al. 2018; Ihedioha et al. 2019).

Such pollutants, which come from human activities (e.g., industrialization, urbanization, and agriculture), are responsible for environmental degradation for and endanger human's health, damage food, and biological resources (Ramade 1989; Kamilou et al. 2014; Ekengele et al. 2015; Tchounda et al. 2019). Heavy metal pollution in rivers has become a matter of great concern over the last decades because of the contamination threat of water resources and the hazards resulting from human consumption of fishery resources (Terra et al. 2008). In Africa, despite poor industrialization, many countries have taken measures to manage aquatic

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resources—that is, by controlling waste discharged into the environment (Okwonko and Mothiba 2005; Assonye et al. 2007).

In Cameroon, few industrial activities are performed but contamination of aquatic milieu by heavy metals has been studied for a number of previous years (Ekengele et al. 2008, 2012; Kwon et al. 2012; Kayalto et al. 2014; Oumar et al. 2014; Nguelieu 2017).. It has been shown that the most frequent heavy metals found in the environment are: zinc, nickel, manganese, copper, chromium, lead, cadmium, and iron (Ekengele et al. 2012; Jallad 2015; Gbogbo et al. 2018; Tchounda et al. 2019). Such metals arise from industrial and agricultural activities and are present in sediments, aquatic products (e.g., fish and shellfish), plants and the human body. So far, no study on this topic has been carried out on rice farms of the Far North Region in Cameroon where agricultural inputs (e.g., pesticides and fertilizers) have been used for more than five decades. Some of the kinds of fish consumed in this region are caught in the rice farms' channels that are contaminated by agricultural inputs. This shows that it is necessary to study the quality of the fish coming from such aquatic milieus.

The main objective of this study, therefore, is to evaluate the level of contamination by heavy metals of fishes caught in the rice farms' channels of in the locality of Pouss to establish the sanitarian risks because of their consumption. Specifically, it was possible to determine the concentration of lead, cadmium, zinc, and copper in the fish and to establish the potential health risks encountered by Pouss inhabitants.

2.2 Material and Methods

2.2.1 Description of the Study Site

The study site, created in 1976, is a collection of rice farms' channels located at Pouss, Maga Sud-Division and Mayo–Danay Division in the Far North Region situated at the Sudano–Sahelian zone of Cameroon. The farms belong to the largest rice-growing area of Maga with about 7000 hectares of developed arable land. The rice cultivation is possible because of the artificial lake (i.e., Maga Lake) integral to the Logone River and another intermittent stream running near the Maga (Fig. 2.1). As in all regions, the locality of Pouss undergoes two seasons with unequal length: the dry season, which lasts 9–10 months (October to July), and the short rainy season, which lasts for 2–3 months (August to September). Annual rainfall ranges from 400–1000 mm and the atmospheric temperature is between 15 and 43 °C (L'hôte 1999).

The soils are mainly argillaceous and become clayey–silty around rice perimeters and temporary streams called Mayos (PNDP/CAFER 2012). Rice is cultivated twice a year, from March to June and from September to December. Apart from rice plants, some grasses (e.g., *Ipomea aquatica*, *Nymphea alba,* and *Echinochloa stagnina*) border rice farms' channels. The three types of channels are: primary

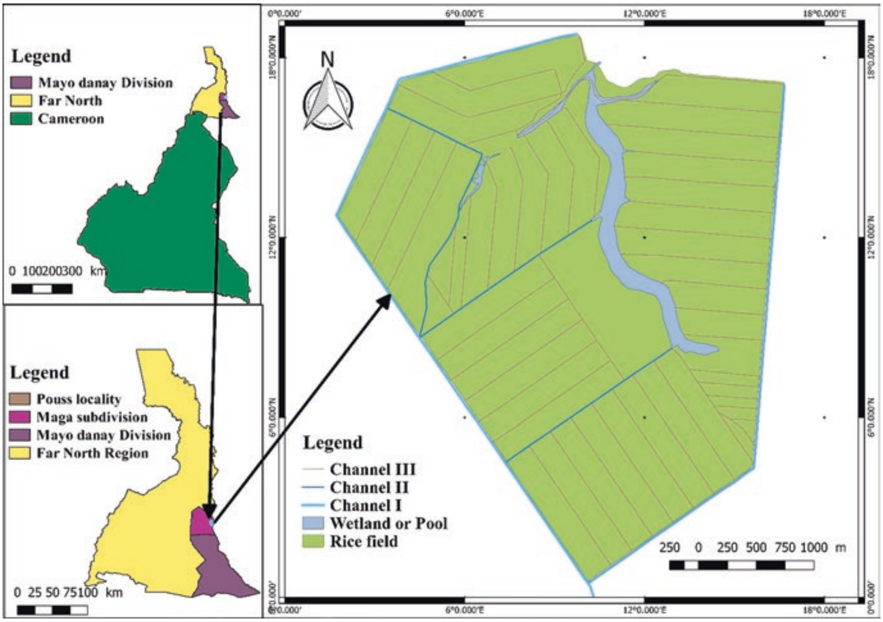

Fig. 2.1 Localization's map of studied site

channel (channel I), which collects water from Lake Maga; secondary channel (channel II), which sends/conveys waters from channel I; into the tertiary channel (channel III), which carries waters from channel II to the rice farms. Fish are caught in all three types of channels.

Several species (e.g., *Tilapia niloticus*, *Clarias gariepinus*, *Alestes baremoze*, *Lates niloticus,* and *Tetraodon*) can be found there. Apart from rice's cultivation, other activities performed in the area are bathing and washing up. During their work, farmers drink water from the channels. The main types of agricultural inputs are ammonium sulfate, urea, and NPK + CaO for fertilizers, and Glyphader 750 SG, Optimal 20 SP, and Assistant 720 SL for pesticides.

2.2.2 *Sampling Method*

For this study, three species of fish caught in the rice farms' channels of Pouss were used: *Alestes baremoze* (Fig. 2.2a), *Tilapia niloticus* (Fig. 2.2b), and *Clarias gariepinus*. (Fig. 2.2c). They are very respected by consumers and are easy to catch during the dry season, which is this book's study period. For each fish, liver, muscles, and gills were analyzed. The fish were sampled in channel II in April 2020 by a fisherman in the study's presence. Four individuals per specie were used to measure the concentrations of chosen heavy metals in the National Laboratory of

Fig. 2.2 Various fish species studied. (**a**) Alestes baremoze, (**b**) Tilapia niloticus, (**c**) Clarias gariepinus

Table 2.1 Length and weight range of fish species collected at Pouss during the study

	Tilapia nilotica	*Clarias gariepinus*	*Alestes baremoze*
Length (cm)	16–18	20–23	22–25
Weight (g)	250–315	268–305	365–370

Analysis of Agricultural Inputs and Products, which is located in Yaoundé—that is, the political capital of Cameroon. Moreover, waters from any rice farm's channel were sampled for further evaluation of the concentrations of heavy metals in the milieu. For that, waters were sampled using 1.5 L of polyethylene bottles.

Fish and water samples were labelled and transported to Maroua town in a thermos flask with ice where they were frozen for 2 weeks. Afterwards, they were transported to the laboratory in a thermos flask and kept frozen until analyses after 2 months was done (June 2020). The length and body weight of each fish were recorded in the laboratory (Table 2.1). The length and weights of three fish species sampled from the rice farms' channels of Pouss varied, respectively, from 16–25 cm and from 250–370 g. Muscles, livers, and gills portions were taken after defrosting.

2.2.3 Measurements of Environmental Parameters

Certain environmental parameters were measured in situ in three types of channels using a multiparameter Extech EC500. These were temperature (°C), pH, electric conductivity (μS/cm), salinity (mg/L), and TDS (mg/L).

2.2.4 Treatment of Fish Samples

Before the analysis of heavy metal, all fish species were treated in the laboratory to obtain a dry mass of fresh organs and muscles. This treatment was conducted in two steps: dissection of the fish and production of dry ash.

2.2.4.1 Dissection of Fish

Dissection consisted of extracting gills, livers, and muscles of each studied fish. This operation took place on a porcelain board and the removed organs were placed in sterilized Petri dishes.

2.2.4.2 Production of Ashes and Extraction Liquid

Ashes of any organ were produced using a drying ash method, which consists of drying, mashing, and calcinating a mass of fresh organ (Pauwels et al. 1992). For that, 25 g of each fresh organ was introduced in a porcelain container and dried at 135 °C/2 h in an ECOCELL oven to obtain a dry sample. This dry sample was transferred into a muffle furnace and the temperature was raised progressively to 450–500 °C. Ashes constituted instantly were moved out and cooled to room temperature after adding 2 mL of concentrated nitric acid for digestion. Digested and dry ashes were transferred back to the furnace during 1 h between 450 and 500 °C. Furthermore, 10 mL of hydrochloric acid (HCl•1N) was added, and the mixture was dissolved on a heating plate. The ash obtained was transferred to a 25 mL volumetric flask, HCl•1N was added up to the mark and the mixture was filtered on Whatmann paper to obtain an extraction liquid.

2.2.5 Measurement of Heavy Metal Concentrations

For this study, the contents of four heavy metals (i.e., Pb, Cu, Zn, and Cd) were evaluated, both in water and fish, by atomic absorption spectrophotometry at a suitable wavelength (Table 2.2).

The concentration of heavy metals in water and in fish organs were calculated using this formula:

$$C = \frac{C_\mathrm{r} \times V_\mathrm{ext}}{P_\mathrm{s}} \quad (\text{Pauwels et al., 1992}),$$

Table 2.2 Heavy metals and wavelength analyzed during study period

Heavy metals	Wavelength (nm)	Equipment brand
Cadmium (Cd)	228.8	Thermo Electron Corporation.S.Serie AA Spectrometer
Lead (Pb)	217.0	
Copper (Cu)	324.7	
Zinc (Zn)	213.9	

where C is the concentration of the measured heavy metal (mg/kg); C_r is the concentration of heavy metal read on a spectrophotometer (mg/L); V_{ext} is the volume of extraction liquid, and P_s is the test quantity.

Likewise, the bioconcentration factor (BCF) of each heavy metal was calculated using a metal concentration in the entire fish or in an organ (mg/kg) over metal concentration in water (mg/kg) (Adhikari et al. 2009) to estimate the capacity of organs and the fish to accumulate heavy metals.

2.2.6 Evaluation of Health Risks

To estimate and characterize health risks because of the consumption of fish caught in the rice farms' channels of Pouss, two indicators were used: estimated daily intake (EDI) of heavy metals and danger ratio (DR), according to Kamilou et al. (2014):

$$\mathrm{EDI} = C \times Q \times \frac{F}{W},$$

where EDI = estimate daily intake (mg/kg/day); C = concentration of heavy metal in fish (mg/kg); Q = quantity of fish ingested daily by adults and children in Cameroon; Q = 0,044 kg/day for adults and children by FAO (2007); F = exposition frequency (F = 1); W = corporal weight mean of consumer in kg, according to FAO (2007).

This is equal to 28 kg for the children (0–15 years) and 70 kg for adults in Cameroon:

$$\mathrm{DR} = \frac{\mathrm{EDI}}{\mathrm{RfD}}$$

and RfD = reference dose (mg/kg/day). If DR <1, the occurrence of a toxic effect is very unlikely; if DR > 1, the occurrence of a toxic effect cannot be excluded.

2.3 Results and Discussion

2.3.1 Environmental Parameters

Water temperature varied from 29.9–39.7 °C. Salinity ranged between 69.5 and 140 mg/L (Table 2.3). The pH values varied between 6.82 and 7.26 (Table 2.3). Electric conductivity (EC) ranged from 125.8–160.2 μS/cm and the TDS values ranged from 89.3–142 mg/L (Table 2.3). Based on these results, waters from rice

Table 2.3 Means and range values of measured environmental variables of water during study period

Parameters	Range	Mean	SD
Temperature (°C)	29.9–39.7	33.02	4.35
Salinity (mg/L)	69.5–140	86.33	30.03
pH	6.82–7.26	7.05	0.15
TDS (mg/L)	89.3–142	119.95	41.34
CE (μS/cm)	125.8–160.2	142.55	11.74

Table 2.4 Mean and range values of heavy metals (mg/kg) in water during study period

	Cd	Pb	Cu	Zn
Channel I	ND	0.23–0.32	0.014–0.068	0–1.119
Channel II	ND	0.51–0.55	0–0.079	0–0.445
Channel III	ND	0–0.67	0–0.066	0–0.873
Mean	*ND*	*0.328*	*0.041*	*0.298*

farms' channels of Pouss are very warm, contain fewer minerals, and are neutral. The right column in the table indicates the standard deviation (SD).

2.3.2 Heavy Metals in Water

The concentrations of heavy metals in water expressed as milligrams per kilogram (mg/kg) were Pb 0–0.67; Cu 0–0.079 and Zn 0–0.873. High concentrations of metals were registered in Channel II and Channel III (Table 2.4). The means values of these metals (Pb: 0.328 mg/kg, Cu: 0.041 mg/kg, Zn: 0.298 mg/kg) show that Pb was higher in water than another metallic atom (concentration order is Pb > Zn > Cu). Cadmium was not detected in the waters. No significant difference was obtained between various channels ($\alpha = 0.05$; p-value = 0.605). No ND was detected.

2.3.3 Metal Levels in Fish Organs

The ranges (and means) of metallic elements expressed as mg/kg based on muscles, gills, and liver of *Alestes baremoze*, *Tilapia niloticus,* and *Clarias gariepinus* are: Pb 0.00–18.00 (3.89); Cu 0.55–9.05 (3.31); Zn 35.56–180.73 (82.35) (Table 2.5). Cd was not detected in any organ of the three species. Pb was detected only in liver. Cu and Zn were more concentrated in liver and gills than muscles. The concentration of Pb was higher in *Clarias gariepinus,* while Cu was more concentrated in *Tilapia niloticus*. Zn was present in *Alestes baremoze* and *Clarias gariepinus*, but higher in *A. baremoze* than in *C. gariepinus*.

Table 2.5 Concentrations of heavy metals (mg/kg) in fishes and organs investigated

Species	Organs	Cd	Pb	Cu	Zn
Alestes baremoze	Gills	ND	0.00[a]	3.00	87.29
	Liver	ND	6.50	4.45	180.73
	Muscles	ND	0.00	0.80	39.03
Clarias gariepinus	Gills	ND	0.00	2.15	105.03
	Liver	ND	18.00	4.35	91.59
	Muscles	ND	0.00	0.95	48.37
Tilapia niloticus	Gills	ND	10.50	4.45	67.46
	Liver	ND	0.00	9.05	86.07
	Muscles	ND	0.00	0.55	35.56
Mean		*ND*	*3.89*	*3.31*	*82.35*

[a]All values are in mg/kg; *ND* = not detected

Table 2.6 Value of bioconcentration factors in each fish's species organ

Organs	*A. baremoze*	*C. gariepinus*	*T. niloticus*
Gills	30.10	35.73	27.47
Liver	63.89	37.98	31.71
Muscles	13.28	16.44	12.04

2.3.4 Bioconcentration Factors

The bioconcentration factor was highest in the liver of all fish species than in the gills and muscles (Table 2.6). It decreased on the order of Zn > Cu > Pb (Table 2.7). The major bioconcentrator of Pb is C*larias gariepinus* (BCF = 19.35), that of Cu is *Tilapia niloticus* (BCF = 117.08), and that of Zn is *Alestes baremoze* (BCF = 426.46).

2.3.5 Human Health Risk Assessment

The estimated daily intake (EDI) and danger ratio (DR) values of measured metals shows that only children exhibit a health risk because of Pb (DR > 1) after consumption of inspected fish (Table 2.8). The DR of adults for Pb, however, moves closer to 1.

Environmental parameters registered during this study (see Table 2.1) show that waters from rice farms' channels of Pouss are favorable for fish farming.

Waters constantly warm is an asset for the development of fish because of the high temperature of waters speeds up metabolism of fish and favors their rapid growth (Baras and Jobling 2002). Nevertheless, exogenous nutrients must be brought into waters to increase the low mineralization, which is good for the development of fish food like planktonic organisms. For this purpose, the rice–fish farmers can use the rice rejects (e,g., cockles and plants) mixed with excrements of cattle

Table 2.7 Bioconcentration factors per fish

Species	Cd	Pb	Cu	Zn
A. baremoze	ND	6.99	68.75	426.46
C. gariepinus	ND	19.35	62.08	340.26
T. niloticus	ND	11.29	117.08	262.63

Table 2.8 Estimated daily intake and danger ratio values for Cu, Pb, and Zn

Metal	*Q* (kg/day)	*C* (mg/kg)	RfD (mg/kg/day)	*W* (kg)		EDI (mg/kg/day)		DR	
				Adult	Child	Adult	Child	Adult	Child
Cd	0.044	0	2.00×10^{-4}	70	28	0.00	0.00	0.00	0.00
Pb	0.044	3.89	3.60×10^{-3}	70	28	2.45×10^{-3}	6.11E-03	0.68	1.70
Cu	0.044	3.31	4.00×10^{-2}	70	28	2.08×10^{-3}	5.20E-03	0.05	0.13
Zn	0.044	82.35	3.00×10^{-1}	70	28	5.18×10^{-2}	1.29E-01	0.17	0.43

collected in the locality to make manure. The use of natural fertilizers thus, limits the degradation of rice ecosystems in addition to increasing the rate of nutrients in water and soil.

The presence of heavy metals in the muscles of fish and in the muscles (see Tables 2.2 and 2.3) highlights the phenomenon of pollution of rice-farms' channels by accumulation of metal pollutants from agricultural inputs and their bioaccumulation in the food chain. Several authors working in the Chad Lake Basin and in Cameroon have reported the degradation of aquatic milieu and the degradation of the quality of fish due to agricultural inputs used to improve agricultural yield (Ekengele et al. 2012, 2015; Kayalto et al. 2014; Oumar et al. 2014; Kayalto 2014). Cadmium was not detected in waters analyzed in this study. It is known that cadmium accumulates better in sediments than water (Ekengele et al. 2012; Smatti-Hamza et al. 2019; Tchounda et al. 2019).

The absence of cadmium in the water has already been reported in the Lake Chad Basin by Kayalto et al. (2014), who worked on the contamination by heavy metals of three fish species (*Lates niloticus*, *Arius latiscutatus*, and *Tilapia nilotica*), waters and sediments of Logon River, Mani River, Chari River, and Chad Lake. Contrary to their works, which also reported the absence of Pb, abnormally high levels of lead have been registered in rice farms' channels of Pouss.

This suggests a gradual accumulation of metal in the water of rice channels that are more stable than previously-mentioned streams. It could be that Pb accumulates better in calm waters than in running waters in the Sudano–Sahelian zone. This suggestion can be confirmed by the works of Kwon et al. (2012) and Oumar et al. (2014), who reported the presence of Pb, respectively, in the Central Lake of Yaoundé and in the Bini and Dang Lakes in the Adamoua Region; that is, the mean of Pb was 2.09 µg/L in Dang and Bini Lakes in Ngaoundéré and 0.052 mg/L in Central Lake of Yaoundé. The rice farmers of Pouss who consume water from rice-farms' channels during their field work run a real risk to their health for the more or less long term (the level of Pb measured during this study was 33 times greater than the standard of WHO (2000) for drinking water).

In addition, the consumption of fish contaminated by lead amplifies the effects of this metal on human health, notably for children. In fact, the metal concentrations in fish registered in this study, except for Cu, were higher than the established toxicological limitation for toxic elements in seafood (WHO 2000) and show the human health risks as a result of the fish consumption studied. The danger ratio (see Table 2.6) however, shows that only children present a real health risk because of Pb (DR > 1) after consumption of *Clarias gariepinus*, *Tilapia niloticus,* and *Alestes baremoze*. This difference between the information shown by standard limitations for toxic elements and the values of DR would be linked to the use of national EDI because of the absence of local EDI and reference doses (RfD) reflecting the real consumption of fish in Far North Region of Cameroon.

In fact, the fish consumed in this Region come mainly from Maga dam (Far North Region) and Lagdo dam (North Region) and their production is not brought into the calculation of national EDI. This situation shows the urgency to establish EDI and RfD adapted to this part of Cameroon. Muscle tissue is the main edible fish part, but in the locality of Pouss and in the Far North Region of Cameroon, the inhabitants eat their muscles, livers, and gills (i.e., only scale and intestines are rejected). Thus, the human health risks increase, especially for children who are fragile owing to the immaturity of their organs. Based on this statement, fish caught from rice farms' channels of Pouss are not advised for human consumption and government should regulate fishing activity in the farms' channels to minimize health hazards caused by unlimited consumption by the population. Government regulations also concern the quality control of agricultural inputs used by rice farmers because surveys have shown that most of the fertilizers and pesticides spread in the rice farms of Pouss are not standardized by the State of Cameroon.

This work demonstrates that heavy metals were more concentrated in liver and gills than in muscles (see Table 2.3) and confirm the differences in concentration of heavy metals in the various tissues (Kayalto et al. 2014; Kayalto 2014; Kamilou et al. 2014; Ekengele et al. 2015). It has been reported that muscles with less a concentrate heavy metals than gills and liver (Ron van der Oost et al. 2003; Kamaruzzaman et al. 2010; Adeyeye and Ayoola 2013; Kayalto et al. 2014; Kayalto 2014; Ekengele et al. 2015). These results were confirmed by the BCF of all fish species studied. It was higher in liver, followed by gills and muscle tissues.

Similar results also were reported in other fish species worldwide (Adhikari et al. 2009; Malik et al. 2010; Alhas et al. 2009; Liu et al. 2012; Kamilou et al. 2014; Ekengele et al. 2015; Smatti-Hamza et al. 2019). Several authors assert that fishes' muscles usually have a low potential for bioaccumulation of metallic substances while it is higher in the liver and gills (Adeyeye and Ayoola 2013; Kamilou et al. 2014; Ekengele et al. 2015; Smatti-Hamza et al. 2019) because muscles are not in direct contact with the external milieu, and they are not an active tissue regarding the concentration of metals (Amundsen et al. 1997; Karadede and Ünlü 2000; Mansour and Sidky 2002; Bajc et al. 2005; El-Moselhy et al. 2014).

Accumulation of heavy metals in fish tissues relies on several factors similar to their environmental concentrations and exposure time, the environmental conditions (temperature, pH), where the fish lived and species-specific living and feeding habits (Henry et al. 2004; Deram et al. 2006; Lalonde et al. 2011; Elnabris et al. 2013). The concentrations of metals registered during this study were higher in fish than in water. The same scheme was reported by Ekengele et al. (2015) in the Municipal Lake of Yaoundé. Markert et al. (1997) stated that the fish tissues contained an additional level of metals than water because metals are taken up from water and concentrated in fish tissues.

Lead was determined in *Clarias gariepinus*, *Alestes baremoze*, and *Tilapia niloticus* (see Table 2.5). They can be used as biological indicators of Pb in the Far North Region of Cameroon. The highest concentration of Pb was detected in the liver of *C. gariepinus* (see Table 2.4); the concentration of Pb is 60 times more than allowed in fish, based on WHO (2000) data. This would be because of the fish's feeding habits, which are detritivore; thus, they would swallow more pollutant when feeding in sediments and water. The gills of *Tilapia niloticus* constitute an effective barrier for the exclusion of Pb in other fish organs. Zn and Cu are essential for fish species, and their bioaccumulation can count among the physiological mechanisms that maintain fish in good health, which can control their content by eliminating in case of high concentration that could produce toxic effects (Clearwater et al. 2002; Javed and Usmani 2016).

Concerning zinc, the level is high in relation to the allowed concentrations for this metal in fish (WHO 2000). Although Zn is essential for the metabolic activities of fish, it would be interesting to watch the concentration of this metal because its accumulative effect, happening during bioconcentration and bioamplification phenomena of heavy metals, produces toxic effects on human health (El Morhit 2009; Boumehres 2010).

2.4 Conclusion

The bioaccumulation of non-essential elements in fish tissue obtained from this study is an indication of the degradation of the rice farms' ecosystems of Pouss because of pesticides and fertilizers spread for a long time. It is also an indication of the danger incurred by those who consume *Alestes baremoze*, *Tilapia niloticus,* and *Clarias gariepinus*, especially the children. These fish species can be used as food markers of heavy metal contamination for rice-farms' channels in the Far North Region of Cameroon. A study of the bioaccumulation of heavy metals on paddy rice produced in this environment, and the health of the population eating these contaminated fish, is urgent so as to establish the solutions aiming to reduce human risks in this area.

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Chapter 3
Evaluation of the Levels of Nine Heavy Metals in Five Crops Using AAS and XRF

Ihesinachi A. Kalagbor

3.1 Introduction

Nigeria is an oil-producing country with the sixth largest oil exports in the world. While oil discovery and exploitation have benefited the Nigerian economy, resulting in fast expansion, the environmental consequences have received less attention. The Niger Delta, the Anambra Basin, the Benue Trough, the Chad Basin, and the Benin Basin have all been explored for crude oil. The region of the Niger Delta appears to be the most promising (Ugbomeh and Atubi 2010). Oil pollution is a risk to the environment as a result of the continual exploration, production, processing, and transportation of crude oil (Agbogidi and Nweke 2005).

Heavy metals are one sort of pollution in our environment, and Nigerian crude oil contains numerous of these heavy metals, including Zn, Al, Ac, As, Fe, Pb, Co, Cu, Cr, Mn, Hg, Cd, Sb, Ni, and V. As a result, plants growing in crude oil-contaminated soils can accumulate large amounts of toxic metals, posing serious health risks when consumed (Nkwocha and Duru 2010). Although metals and metalloids occur naturally in crude oil, they can also be added during the production, transportation, and storage processes. These elements exist as inorganic salts (mostly chlorides and sulphates of K, Mg, Na, and Ca) or as organometallic compounds of Ca, Cu, Cr, Mg, Fe, Ni, Ti, V, and Zn (Speight 2001). A number of chemical variables and heavy metal transport influences metal interactions with soil solid phases, water, and air within and above the soil. Metal absorption from soil water to

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soil particles is the primary chemical factor limiting soil mobility (Curtis and Smith 2002).

According to research, plants growing in locations contaminated with heavy metals frequently acquire heavy metals via deposits on plant parts exposed to polluted air and soils (Khairiah et al. 2004), Singh and Kumar (2006), and Sharma et al. (2008). By accumulating to levels that pose a considerable risk to human health when consumed, the high concentration of heavy metals in soil may signal a comparable concentration in plants (Singh et al. 2010). As a result, it is critical to detect heavy metals in environmental samples (Musah et al. 2013). They are significant environmental contaminants, and their toxicity is a source of concern for a variety of reasons, including health, ecological, evolutionary, nutritional, and environmental problems (Chakraborty et al. 2013; Jaishankar et al. 2014; Nagayoti et al. 2010).

Enrichment of heavy metals in terrestrial environments in the Niger Delta is primarily due to oil spillage (Idodo-Umeh and Ogbeibu 2010). When an oil spill happens without prompt response, the oil seeps into the ground and spreads to low-lying areas. By allowing oil to drain into neighbouring farms, ponds, swamps, and creeks, rainfall aids in the spread of oil. Root crops such as cassava are among the crops that will become useless in the area (UNEP 2011). Long-term exposure to high amounts of heavy metals is one of the most serious dangers linked with oil contamination (Osuji and Onojake 2004; Nkwocha and Duru 2010). The majority of Niger Delta states derive their revenue mostly from indigenous farming and fishing, with cassava, yam, maize, cocoyam, and plantain serving as the predominant food crops in the region, along with vegetables (Gideon-Ogero 2008).

Several previous researches (Agbogidi et al. 2007; Gideon-Ogero 2008; Idodo-Umeh and Ogbeibu 2010; Nkwocha et al. 2011; Okoye and Okwute 2014; Kalagbor et al. 2015a, b; Nteranya 2015; Okereke et al. 2016; Ogunlesi et al. 2017; Emurotu and Onianwa 2017; Olutosin and Barbara 2019) have demonstrated a substantial accumulation of heavy metals in several edible food crops grown in locations with pollution. Corrosion of metallic objects leads to ground contamination by heavy metals. Nkwocha et al. (2011) investigated the concentration levels of some heavy metals in tuber crops grown around Etelebou oil flow station in Bayelsa state, Nigeria. These tuber crops (cassava, plantain, and cocoyam) were observed to have high concentrations of Fe, Zn, Cr, Cu, and Pb. Similar findings were obtained in the studies carried out by Oladebeye (2017), on the assessment of heavy metals in Nigerian vegetables and soil in Owo and Edo axis of Ondo state using X-ray Fluorescence (XRF) techniques. The study could not detect Ni, Cd, Co, and Cu in both vegetables and soil samples.

3.1.1 Research Problem

In spite of the pause in Ogoni territory's oil production operations, the land's entire range of oil operations took place on highly rich soil. In some cases, decommissioned oil facilities were never legally decommissioned, while in other cases they were abandoned, as per the UNEP (2011) study. Figure 3.1 shows what happens when things are left unattended and exposed to the elements for an extended period. It shows the location of a defunct oil well head in the middle of a vast oil field.

The picture was taken during the rainy season which explains the waterlog. The soil is no longer as productive as it used to be but the farmers apply ample quantities of fertilizer to boost the yield. During the dry season, the soil is dry, black, and crusted. These abandoned facilities pose both environmental and safety risks.

Agbogidi et al. (2007) discovered a buildup of heavy metals in crude oil-contaminated soils in Asaba and Ozoro. The contents of Fe, Zn, Cu, Mn, Pb, Cd, Cr, and Ni in soil were significantly higher in crude oil-contaminated soils. Many farmers are unaware of the detrimental consequences of agricultural cultivation on contaminated soils. As a result, harvested crops may contain heavy metals (Grigg 2004). Sequel to the findings by Kalagbor et al. on fruits (2014a, b), vegetables (2014c), and crops (2015a, b) this study was proposed to evaluate the levels of nine heavy metals present in five crops (cassava, three-leaved yam, water yam, white yam, and maize) from three farmlands in Kpean and Zaakpon communities.

3.1.2 Study Area

Oil spills are frequent events in Ogoni land. For example, oil pollution can cause stress and even death to plants when it enters the root zone of trees and other vegetation (UNEP 2011; Mckelvey et al. 2007). Another major worry associated with oil pollution is the long-term exposure to high levels of heavy metals from oil (Nkwocha and Duru 2010). There are several residences in the Ogoni community that are within walking distance of oil field facilities according to UNEP's (2011) assessment of the oilfield on Ogoni land. The three farmlands (100 m^2 each) used for this study are in Khana Local Government Area. The farmlands in Kpean are in two different locations. One was at an oil spill site (Site K_2) and the other (Site K_1) was about 3 km into the village from the oil spill location while the third farmland is situated in Zaakpon community (Figs. 3.1 and 3.2). The occupation of the people is predominantly farming and fishing. During each planting season, the farmers move in droves carrying their crops and seedlings such as cassava, plantain, three-leaved yam, white yam, water yam, melon as well as vegetables and maize to plant. These are the staple foods of the people. This study was conducted for 2 years to cover two planting seasons giving the cassava enough time to mature and attain the edible stage before being processed into garri.

Fig. 3.1 Map showing Zaakpon farm

Fig. 3.2 Map showing Kpean and Oil location farms

3.2 Materials and Methods

3.2.1 Materials and Farmlands

Three farms were used in this study, and they are located in two distinct communities within Rivers State's Khana Local Government Area. One farm had experienced oil spill in the year 2000 and is located in Zaakpon. Another is an abandoned oil spill site (referred to as Oil Location by the indigenes) while the third farm (Kpean) is about 3 km into the village away from the oil location farm (Fig. 3.3). Maize (grain) and four crops (cassava, white yam, three-leaved yam, and water yam) were used for this study. These are the major staple food crops for the indigenes.

3.2.2 Sample Collection and Planting

The four crops and maize were selected out of many crops and grains that the farmers in these communities cultivate for the purposes of this study. The crops and maize used were purchased at different market days. These were divided into two portions. One portion was dried and digested in duplicates with acid mixture and analyzed as the baseline samples while the other portion was planted. The crops and the maize were planted without the addition of fertilizer to the soils. These crops have a shorter maturation period which enabled us plant, harvest, and analyze our samples within the specified period of study. Maize was harvested 3 months after planting, while the varieties of yams were harvested after 9 months of planting.

Fig. 3.3 Farm at oil location (K_2)

Cassava was harvested at three different stages: 9 months, 12 months, and 18 months. Before planting, the farmlands were cleared and soil samples were taken from the three farms at 30 cm and 60 cm depth. These were digested and analyzed as baseline for our study.

The farmers from these communities employed a mixed crop method of farming according to the recommended planting spacing for each crop. The experiment set-up was randomized block design.

3.2.3 Monitoring of Farms and Crops

The farms were monitored weekly and clearing of the weeds was carried out frequently especially during the rainy season by farm helps engaged for purposes of this study. Stunted growths were observed among the crops when compared with those in adjourning farms that had been planted with the addition of fertilizer.

Diseases especially at the oil location farm attacked the crops. Yellow coloration of the leaves was noted. The soil surface at this site was very dark showing traces of crude oil in contrast to the soil at Kpean farm (Site K_1).

Crop yields from oil location (Site K_2) were very poor and badly diseased. From Kpean farm, the yields were quite minimal, whereas from Zaakpon farm, good yields were obtained for all the crops planted and none was diseased. The soil was not dark (as in oil location) but brown and the texture was loamy.

3.2.4 Harvesting

From the three farms, samples were selected for maize after 3 months of planting for digestion and analysis using AAS and XRF. After 9 months of planting, the cassava, white yam, water yam, and three-leaved yams were harvested, digested, and analyzed. Portions of cassava were left in the three farms to be harvested at 12 months and 18 months after planting and processed into the edible form (garri). This is to simulate the farmer’s full agricultural activity with respect to this particular crop from cultivation to consumption. The farms were monitored from time to time. The last harvesting of cassava was carried out at 18 months.

3.2.5 Sample Preparation

At maturation, the samples were harvested from the three farms, peeled and sliced into little sizes (in the case of the crops), and kept in the open to air-dry for 3 days. The drying was rapid because of the harmattan weather. The maize kernels were removed from the cob and left to dry in the open to reduce moisture content. Using a polyurethane mortar and pestle, the dry materials were ground into a fine powder. They were then separated into sample containers, labelled, and set away for digestion and analysis. To eliminate moisture and maintain a constant aggregate weight, the soil samples were left to air-dry for 3 days. Using a polyurethane mortar and pestle, the dry materials were ground into a fine powder. They were then separated into sample containers, labelled, and set away for digestion and analysis. To eliminate moisture and maintain a constant aggregate weight, the soil samples were left to air-dry for 3 days.

3.2.6 Sample Digestion

Sample Digestion for AAS analysis

Digestive mixture of perchloric acid (1:4 v/v) BDH analaR grade was used to extract the soil samples in pre-washed glass beakers for an hour at room temperature. Deionized water was used to dilute the filtrate in 50 ml volumetric flasks, where it was filtered using Whatman filter papers. Samples (10 ml) of the resulting solutions were placed in test bottles for AAS analysis.

Using an analytical balance, weigh 1 g of each sample, add 10 ml of the digestion mixture of perchloric and nitric acid (1: 4 v/v) BDH analaR grade to the breakers, then let stand for 15 minutes before analysing. After heating for 4 hours to ensure thorough digestion, the contents were cooled and filtered into volumetric flasks of 50 ml before being made up to the mark with deionized water. Sample vials containing 10 ml of the resulting solutions were used for AAS analysis. A single beam spectrometer was used in which a blank reading was taken first. Appropriate lamps were selected for the different elements. The aqueous samples were aspirated into the flame atomizer and measured at parts per million (ppm) concentration using AAS model AA500 (PG instrument).

Sample Preparation for XRF Analysis

The soil samples were packaged in clean plastic sample containers and labelled appropriate for XRF analysis. Ground maize and crop samples were also packaged and labelled properly for the XRF analysis by the Materials Science and Engineering Laboratory of Kwara State University, Malete, Nigeria, where each sample was uniformly homogenized using a pulverizing mill and a sample press. The samples were prepared as pressed pellets and analyzed using the XRF spectrometer by Jiangsu Skyray Instrument Company.

3.3 Results and Discussion

Results from AAS Analysis

Table 3.1 shows the metal concentrations in the baseline samples (taken before planting). No traces of Cr, Co, Cu, or Cd were found in the samples. Tables 3.2, 3.3, 3.4, and 3.5, however, show that these metals were identified in the harvested samples.

Samples of white yam and maize were the only ones to have Pb, while samples of yams other than white were devoid of Mn. Table 3.2 shows the total metal concentrations in the soil samples collected from the three farms. The average values of soil samples taken at 30 cm and 60 cm depths from each farm are used to calculate the results. These soil samples and the control sample contained no trace amounts of Cr, Co, Cu, or Cd. There were higher levels of Mn, Zn, and Pb in the control soil samples compared to the agricultural soil samples. Compared to the soil samples from farms, the control soil samples had lower quantities of Fe and Ni. In the harvested samples from Kpean farm, white yam had the highest concentrations of Cr, Co, Ni, Cu, and Pb, whereas three-leaved yam had the highest concentrations of Mn (Table 3.3). Maize had the highest concentration of Zn and Cd, while cassava had

Table 3.1 Concentration of the metals (mgkg^{-1}) in the baseline samples before planting *(AAS)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava K_1	–	–	6.35	94.00	5.15	44.75	–	–	–
Cassava Z_1	–	–	6.35	62.70	9.85	34.20	–	–	–
Water yam K_1	–	–	–	81.35	5.15	39.90	–	–	1.65
Water yam Z_1	–	–	–	80.10	5.15	54.40	–	–	1.65
Maize K_1	–	–	4.45	25.35	5.15	88.70	–	–	–
Maize Z_1	–	–	11.35	31.95	2.80	89.60	–	–	–
Three-leaved yam K_1	–	–	–	89.05	12.20	43.00	–	–	–
Three-leaved yam Z_1	–	–	–	94.55	12.20	43.00	–	–	–
White yam K_1	–	–	–	67.10	5.15	49.60	–	–	5.75
White yam Z_1	–	–	–	72.60	5.15	64.55	–	–	5.75

Table 3.2 Concentration of the metals (mgkg^{-1}) in the baseline soil samples before planting *(AAS)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Kpean soil (K_1)	–	–	8.55	1253.00	9.50	22.75	–	–	5.75
Oil location soil (K_2)	–	–	12.65	2165.00	14.55	28.50	–	–	7.85
Zaakpon soil (Z_1)	–	–	15.20	1934.00	16.90	26.75	–	–	7.85
Minimum	–	–	8.55	1253.00	9.50	22.75	–	–	5.75
Maximum	–	–	15.20	2165.00	16.90	28.50	–	–	7.85
Mean	–	–	12.03	1754.00	13.47	25.85	–	–	7.01
Std dev.	–	–	3.34	466.97	3.75	2.92	–	–	1.15
Control	–	–	195.80	927.30	10.25	167.00	–	–	14.5

Table 3.3 Concentration of the metals ($mgkg^{-1}$) in the harvested samples from Kpean farm *(AAS)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	42.10	8.55	18.05	66.85	22.60	9.95	13.55	0.35	11.20
Three-leaved yam	23.95	7.65	32.30	64.20	29.70	10.15	13.00	0.35	11.20
Water yam	39.05	6.75	13.50	62.85	8.45	16.40	13.55	0.75	5.75
White yam	48.10	12.20	14.80	57.60	43.90	12.90	18.30	0.35	18.25
Maize	33.00	5.80	24.50	40.45	15.55	33.05	16.30	0.75	–
Minimum	23.95	5.80	13.50	40.45	8.45	9.95	13.00	0.35	5.75
Maximum	48.10	12.20	32.30	66.85	43.90	33.05	18.30	0.75	18.25
Mean	37.24	8.19	20.63	58.39	24.04	16.49	14.94	0.76	14.25
Std dev.	9.21	2.46	7.79	10.58	13.64	9.62	2.28	0.51	7.18

Table 3.4 Concentration of the metals ($mgkg^{-1}$) in the harvested samples from oil location *(AAS)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	51.15	9.45	24.50	62.85	15.55	10.40	13.00	1.60	21.80
Three-leaved yam	39.05	8.55	40.05	73.40	8.45	31.80	18.30	1.20	7.60
Water yam	39.05	6.75	15.45	61.55	15.55	14.90	19.35	0.35	7.60
White yam	42.20	9.47	14.15	64.20	29.70	11.65	15.10	0.35	18.25
Maize	42.10	7.65	25.15	48.35	13.50	30.30	13.55	0.75	–
Minimum	39.05	6.75	14.15	48.35	8.45	10.40	13.00	0.35	7.60
Maximum	51.15	9.47	40.05	73.40	29.70	31.80	19.35	1.60	21.80
Mean	42.71	8.37	23.86	62.07	16.55	19.81	15.86	0.60	11.16
Std dev.	4.97	1.17	10.36	8.97	7.90	10.40	2.84	0.38	5.02

the highest concentration of Fe. There was a high quantity of Mn, Fe, and Zn in the three-leaved yam samples from the oil location, as shown in Table 3.4, while Co and Ni were identified in the white yam from this area. The highest levels of Cr, Cd, and Pb were found in cassava. White yam's highest Cr concentration was found in maize. Co, Ni, Fe, and Cd concentrations in white yams from Zaakpon farm were the highest in Table 3.5. Pb was found at the highest amounts in the three-leaved yam, while Cu was found in the highest concentrations in the water yam variety. There were the greatest levels of Mn and Zn in corn. As with white yam, it exhibited significant levels of Co as well. The most Cr was found in cassava, by far. This investigation found that Cr, Co, Ni, and Fe concentrations were higher than those found by Agbogidi et al. (2007). There was no trace of Pb in any of the three maize samples that were taken from the three farms. Cassava and maize baseline samples had Mn amounts recorded, while yam variants did not (water yam, three-leaved yam, and white yam). Mn concentrations in the harvested yams were higher and occasionally equal to those detected in the soil samples, but this was not the case with other kinds. The baseline Mn concentrations in cassava and maize were lower than those found in soil samples, while harvested samples were higher. Mn concentrations in the harvested samples were found to be four to five times higher than in the original samples. The findings of Agbogidi et al. (2013) are comparable to this

Table 3.5 Concentration of the metals (mgkg^{-1}) in the harvested samples from Zaakpon farm *(AAS)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	57.20	4.90	30.10	52.30	15.55	11.90	15.10	0.35	7.60
Three-leaved yam	20.90	10.20	29.70	61.55	29.70	13.65	13.55	0.75	25.35
Water yam	39.05	6.75	14.80	66.85	29.65	24.10	20.90	0.35	11.20
White yam	51.15	10.42	18.05	74.75	29.90	12.90	17.25	1.20	21.80
Maize	45.10	10.40	33.60	54.95	8.45	38.00	13.00	0.35	–
Minimum	20.90	4.90	14.80	52.30	8.45	11.90	13.00	0.35	7.60
Maximum	57.20	10.42	33.60	74.75	29.90	38.00	20.90	1.20	25.35
Mean	42.68	8.53	25.25	62.08	22.65	20.11	15.96	0.60	16.49
Std dev.	13.93	2.56	8.28	9.08	10.04	11.15	3.22	0.38	8.44

Table 3.6 Concentrations of the metals (mgkg^{-1}) in baseline samples before planting *(XRF)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava K_1	0.001	–	0.006	0.141	0.092	0.212	0.355	–	–
Three-leaved yam K_1	0.006	–	0.002	0.139	0.091	0.180	0.159	–	–
Water yam Z_1	0.004	–	0.004	0.199	0.085	0.184	0.284	–	–
White yam K_1	0.002	–	0.002	0.148	0.081	0.201	0.368	–	–
Maize K_1	0.005	–	0.004	0.157	0.104	0.224	0.227	–	–
Maize Z_1	0.003		0.009	0.342	0.096	0.243	0.261	–	–

one. Each of the harvested crops had somewhat higher Fe contents than those found in the soil samples. Ni concentrations in the harvested crops and maize above the FAO/WHO permissible limit of 67.90 mgkg^{-1}, particularly for the yam cultivars, but were still within the acceptable range. Varga et al. (1999) found that increased Mn buildup occurs when there is an increase in Ni concentrations. According to the results, this is correct. Cd deficiency in soil also reduces the uptake of Fe. This explains why Fe concentrations in crop samples are so low, despite the fact that soil samples have extremely high Fe concentrations. Even while Zn concentrations were determined to be within permissible levels of 99.40 mgkg^{-1}, they were found to be greater in the baseline samples than in the soil samples and the harvested samples. The elevated Zn concentration values in the baseline samples must have come from maize that was grown in polluted soil. Zn concentrations in harvested samples from Zaakpon range from 11.90 to 38.0 mgkg^{-1}.

Results for XRF Analysis

From the XRF analyses for the presence of the heavy metals presented in Tables 3.6, 3.7, 3.8, 3.9, and 3.10, results showed very low concentrations (0.001–0.007) for Cr for the baseline and harvested samples (Table 3.6). Soil samples from Kpean (K_1), Oil location (K_2) and Zaakpon (Z_1) had concentrations of 0.002, 0.013, and 0.008 respectively. Co, Cd, and Pb were not detected in the baseline, soil, and harvested samples. Mn concentrations in baseline and harvested samples were low (0.002–0.014) with three-leaved yam and maize having the higher concentration for the harvested crops from each farm. This is in agreement with the results from AAS

Table 3.7 Concentrations of the metals (mgkg^{-1}) in the soil samples *(XRF)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
SS K_1	0.002	–	0.038	7.529	0.103	0.167	0.115	–	–
SS K_2	0.013	–	0.030	10.240	0.106	0.170	0.098	–	–
SS Z_1	0.008	–	0.042	9.594	0.103	0.169	0.137	–	–
Minimum	0.002	–	0.030	7.529	0.103	0.167	0.098	–	–
Maximum	0.013	–	0.042	10.240	0.106	0.170	0.137	–	–
Mean	0.008	–	0.037	9.121	0.104	0.169	0.117	–	–
Std dev.	0.006	–	0.006	1.416	0.002	0.002	0.020	–	–

Table 3.8 Concentration of the metals (mgkg^{-1}) in the harvested samples from Kpean farm *(XRF)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.005	–	0.005	0.133	0.097	0.163	0.121	–	–
Three-leaved yam	0.006	–	0.010	0.137	0.089	0.154	0.060	–	–
Water yam	0.007	–	0.003	0.143	0.084	0.161	0.117	–	–
White yam	0.004	–	0.002	0.122	0.091	0.155	0.099	–	–
Maize	0.003	–	0.011	0.217	0.091	0.209	0.152	–	–
Minimum	0.003	–	0.002	0.122	0.084	0.154	0.060	–	–
Maximum	0.007	–	0.011	0.217	0.097	0.209	0.152	–	–
Mean	0.005	–	0.006	0.150	0.090	0.168	0.110	–	–
Std dev.	0.002	–	0.004	0.038	0.005	0.023	0.034	–	–

Table 3.9 Concentration of the metals (mgkg^{-1}) in the harvested samples from oil location farm *(XRF)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.004	–	0.008	0.137	0.083	0.155	0.103	–	–
Three-leaved yam	0.004	–	0.014	0.133	0.092	0.163	0.204	–	–
Water yam	0.006	–	0.003	0.116	0.094	0.170	0.176	–	–
White yam	0.003	–	0.002	0.138	0.085	0.168	0.168	–	–
Maize	0.004	–	0.012	0.154	0.106	0.242	0.261	–	–
Minimum	0.003	–	0.002	0.116	0.083	0.155	0.103	–	–
Maximum	0.006	–	0.014	0.154	0.106	0.242	0.261	–	–
Mean	0.004	–	0.008	0.136	0.092	0.180	0.182	–	–
Std dev.	0.001	–	0.005	0.014	0.009	0.035	0.057	–	–

compared to those recorded for the soil samples from the three farms (0.030–0.042). The concentrations of Fe in the soil samples from the three farms (Table 3.7) were found to be very high (7.529, 10.240, and 9.594) when compared to the values obtained for the baseline samples (0.139–0.342) and the harvested samples (0.116–0.300). From these data, all the harvested crops and maize had Fe concentrations that were lower than the baseline samples. This finding is in agreement with

Table 3.10 Concentration of the metals (mgkg^{-1}) in the harvested samples from Zaakpon farm *(XRF)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.005	–	0.008	0.133	0.086	0.162	0.048	–	–
Three-leaved yam	0.003	–	0.010	0.141	0.080	0.178	0.089	–	–
Water yam	0.002	–	0.002	0.121	0.081	0.181	0.127	–	–
White yam	0.007	–	0.003	0.124	0.094	0.147	0.078	–	–
Maize	0.006	–	0.014	0.300	0.092	0.250	0.117	–	–
Minimum	0.002	–	0.002	0.121	0.080	0.147	0.048	–	–
Maximum	0.007	–	0.014	0.300	0.094	0.250	0.127	–	–
Mean	0.005	–	0.007	0.164	0.087	0.184	0.092	–	–
Std dev.	0.002	–	0.005	0.077	0.006	0.040	0.032	–	–

the results obtained using AAS. Ni concentrations (0.081–0.106) were recorded for the baseline samples and for the soil samples (0.103 and 0.106). The harvested samples had Ni concentrations of 0.080–0.097 (Tables 3.8, 3.9, and 3.10). These indicate that there was no appreciable change in the levels of Ni for both baseline and harvested samples. Results obtained for Zn concentrations (Tables 3.8, 3.9, and 3.10) show that the values from all the harvested samples were lower (0.147–0.250) compared to the values obtained for the baseline samples (0.180–0.243) and the soil samples (0.167, 0.170, 0.169). This observation is in agreement with the results obtained from AAS. Harvested samples had lower concentrations (0.060–0.261) of Cu as presented in Tables 3.8, 3.9, and 3.10 than the baseline samples (0.159–0.368). Cd and Pb were not detected for baseline, soil, and harvested samples. The Zn concentrations in the harvested samples were twice those of Ni, while the levels of Mn were 10–40 times lower than the corresponding Ni concentrations.

Statistical Analysis

Results from the two-way analysis of variance (ANOVA) for AAS and XRF results showed that there was obvious interaction effect of soil on crop based on the concentration of all the heavy metals at the significant value of $p < 0.001$ except Cu with partial eta value of virtually 0.80–0.99. This therefore means that the 80–99% variation can be attributed to the interaction of the crop on a location (soil) except in the case of Cu. There is also a main effect of the soil on the concentration of all the heavy metals except for Cr and Cu with partial eta value of virtually 0.99. Interestingly, there is also a main effect of crop on the concentration of all the heavy metals with partial eta value of 0.895. The post hoc shows that the mean difference is statistically significant.

Pollution Load Index (PLI)

Cr, Co, Cu, and Cd were not detected as shown in Table 3.2. Zn concentrations were very low (22.8–28.5 mgkg^{-1}), while Fe concentrations were very high (1253–2165 mgkg^{-1}). Both AAS and XRF results showed that the soil from oil location had the highest values for all the metals followed by the soil from Zaakpon farm then Kpean farm. After iron (Fe), we have zinc (Zn), nickel (Ni), iron (Mn), and lead (Pb). Experimentation farms yielded minimal levels of these metals, except for Fe, in comparison to the FAO/WHO permissible limits. The values obtained from the reference soil were within the acceptable limits (FAO/WHO). Cd was not detected in the baseline and soil samples, but low concentrations of this metal were recorded for all the harvested crops from the three farms. The soil samples had Pb concentrations of 5.75 $mgkg^{-1}$, 7.85 $mgkg^{-1}$, and 7.85 $mgkg^{-1}$for Kpean (K_1), oil location (K_2), and Zaakpon (Z_1), respectively. All the harvested samples except maize had Pb concentrations higher than those recorded for the baseline and soil samples.

$$\text{Pollution Load Index } (\text{PLI}) = \frac{C_{\text{soil sample}}}{C_{\text{reference}}} \tag{3.1}$$

According to Lui et al. (2005), the pollution load index (PLI), which quantifies the degree of pollution caused by each metal in comparison to a reference value, was 0.06, 1.92, 1.04, 0.16, and 0.49 for the metals Mn, Fe, Ni, Zn, and Pb, respectively (Table 3.11a). The pollution load index (PLI) is a metric that indicates the extent to which a metal is polluted in contrast to a reference value. According to Eq. (3.1), the PLI indices for Fe at the three farm locations and for Ni at the oil location and Zaakpon farms are more than 1, indicating that soils have been contaminated with heavy metals. This is consistent with the high values obtained from oil locations and Zaakpon farms that were harmed by the oil spills. According to Lacatusu, a contamination/pollution score of 0.76–1.00 indicates extremely severe contamination, whereas indices of 1.1–2.0 indicate slight pollution and indices 2.0–4.0 indicate moderate pollution (2000). Table 3.11b contains the contamination/pollution index. The degree of contamination detected in this study ranges from negligible (for Ni) to high (for Fe), whereas Zn exhibits only little contamination (0.39–0.54) and Pb exhibits moderate to severe contamination (0.39–0.54), respectively. Numerous researchers have documented the accumulation of heavy metals in soils contaminated with crude oil in the Niger Delta, Agbogidi et al. (2007), Idodo-Umeh and Ogbeibu (2010), Nkwocha et al. (2011), Okoye and Okwute (2014), and Kalagbor et al. (2015a), to name a few.

Table 3.11a Pollution Load Index (PLI) for the soil samples

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Kpean soil (K_1)	–	–	0.044	1.351	0.927	0.136	–	–	0.397
Oil location soil (K_2)	–	–	0.065	2.335	1.420	0.171	–	–	0.541
Zaakpon soil (Z_1)	–	–	0.078	2.086	1.649	0.160	–	–	0.541
Average	–	–	0.062	1.924	1.332	0.156	–	–	0.493

NB: C_{soil} reference is from an area in Port Harcourt of non-oil exploration or production activity

Table 3.11b Significance of intervals of contamination/pollution index

C/PI	Significance
<0.1	Very slight contamination
0.10–0.25	Slight contamination
0.26–0.50	Moderate contamination
0.51–0.75	Severe contamination
0.76–1.00	Very severe contamination
1.10–2.00	Slight pollution
2.10–4.00	Moderate pollution
4.10–8.00	Severe pollution
8.10–16.00	Very severe pollution
>16.00	Excessive pollution

Adapted from Lacutusu (2000)

Plant Concentration Factor (PCF)

The plant concentration factor was used to evaluate the accumulation of heavy metals in the food crops examined (PCF). To put it another way, Cui et al. (2005) define this as the proportion of heavy metals in the experimental farm's contaminated soil to the food crop's heavy metal concentration (C_{plant}).

$$\text{Plant Concentration Factor}\left(\text{PCF}\right) = \frac{C_{plant}}{C_{soil}} \quad (3.2)$$

These PCF indices are presented in Tables 3.12, 3.13, and 3.14 (for AAS) and Tables 3.15, 3.16, and 3.17 (for XRF). A PCF value of less than 0.99 indicates that the plant has the potential to acquire the heavy metal. The findings of the AAS analysis using Eq. (3.2) indicated that the Mn concentrations in soil samples were lower than those in harvested samples, resulting in high PCF indices of 0.974–3.778. These values show that there is a bioaccumulation of Mn from these farm sites. PCF indices for Fe were very low (0.022–0.053) from AAS analysis showing that there is no appreciable transfer of this metal from the soils to the plants in these three farms. These indices are even lower (0.011–0.031) from the XRF analysis using Eq. (3.2). Similar to Mn results, the PCF indices for Ni were mostly high (1.637–4.621) for all the crops from Kpean farm except water yam (0.889). These indices were also high for cassava (1.069), water yam (3.017), and white yam (2.041) from oil location. For the crops harvested from Zaakpon farm, only the yam varieties had high PCF indices of 1.754, 1.757, and 1.769 for water yam, three-leaved yam, and white yam respectively. PCF values of 1.16–1.42 for Zn were recorded for maize as it was the only crop that had PCF $\geq$0.99 in the three farms followed by three-leaved yam (1.12) from oil location. All the crops from the three farms had high PCF indices for Pb (0.968–3.791) except maize which had no Pb detected in the harvested samples.

Table 3.12 Plant Concentration Factor (PCF) Kpean farm K_1, *(AAS)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	–	–	2.111	0.053	2.379	0.437	–	–	3.791
Three-leaved yam	–	–	3.778	0.051	3.126	0.446	–	–	2.122
Water yam	–	–	1.579	0.050	0.889	0.721	–	–	0.096
White yam	–	–	1.731	0.046	4.621	0.567	–	–	3.174
Maize	–	–	2.865	0.032	1.637	1.332	–	–	–

Table 3.13 Plant Concentration Factor (PCF) Location farm K_2, *(AAS)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	–	–	1.937	0.029	1.069	0.365	–	–	1.427
Three-leaved yam	–	–	3.166	0.034	0.581	1.116	–	–	0.968
Water yam	–	–	1.119	0.030	3.017	0.409	–	–	0.968
White yam	–	–	1.221	0.028	2.041	0.523	–	–	2.325
Maize	–	–	1.988	0.022	0.093	1.160	–	–	–

Table 3.14 Plant Concentration Factor (PCF) Zaakpon farm Z_1, *(AAS)*

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	–	–	1.980	0.027	0.920	0.445	–	–	0.968
Three-leaved yam	–	–	1.954	0.032	1.757	0.510	–	–	3.229
Water yam	–	–	0.974	0.035	1.754	0.901	–	–	1.247
White yam	–	–	1.188	0.039	1.769	0.482	–	–	2.777
Maize	–	–	2.211	0.028	0.500	1.421	–	–	–

Table 3.15 Plant Concentration Factor (PCF) Kpean farm, K_1, *(XRF)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	3.00	–	0.263	0.018	0.864	0.922	0.774	–	–
Three-leaved yam	2.50	–	0.132	0.018	0.942	0.976	1.052	–	–
Water yam	3.50	–	0.079	0.019	0.816	0.964	1.017	–	–
White yam	3.50	–	0.053	0.016	0.883	0.928	0.861	–	–
Maize	–	–	0.289	0.029	0.883	1.251	1.322	–	–

Table 3.16 Plant Concentrations Factor (PCF) location farm K_2, *(XRF)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.308	–	0.267	0.013	0.783	0.912	1.051	–	–
Three-leaved yam	0.308	–	0.467	0.013	0.868	0.959	0.612	–	–
Water yam	0.462	–	0.100	0.011	0.887	1.000	1.796	–	–
White yam	0.231	–	0.067	0.013	0.802	0.988	1.714	–	–
Maize	0.308	–	0.400	0.015	1.000	1.424	2.663	–	–

Table 3.17 Plant Concentrations Factor (PCF) Zaakpon farm *(XRF)*

Samples	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.625	–	0.190	0.014	0.835	0.959	0.350	–	–
Three-leaved yam	0.375	–	0.238	0.015	0.777	1.053	1.489	–	–
Water yam	0.250	–	0.048	0.013	0.786	1.071	0.927	–	–
White yam	0.875	–	0.071	0.013	0.913	0.869	0.569	–	–
Maize	0.750	–	0.333	0.031	0.893	1.480	0.854	–	–

Table 3.18 Concentration of the metals (mgkg^{-1}) for unprocessed cassava at 9 months

Farm	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Kpean	42.10	8.55	18.05	66.85	22.60	9.95	13.55	1.60	21.80
Oil location	51.15	9.45	24.50	62.85	15.55	10.40	13.00	0.35	11.20
Zaakpon	57.20	4.90	30.10	52.30	15.55	11.90	15.10	0.35	7.60
Minimum	42.10	4.90	18.05	52.30	15.55	9.95	13.00	0.35	7.60
Maximum	57.20	9.45	30.10	66.85	22.60	11.90	15.10	1.60	21.80
Mean	50.15	7.63	24.22	60.67	17.90	10.75	13.88	0.77	13.53
Std dev.	6.78	2.11	5.39	6.64	3.46	0.90	0.96	0.61	6.51

Table 3.19 Concentration of the metals (mgkg^{-1}) for processed cassava (garri) at 12 months

Farm	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Kpean	10.30	1.65	7.80	31.80	15.30	10.95	14.90	–	–
Oil location	16.85	4.00	12.75	46.45	16.30	12.10	15.45	–	–
Zaakpon	11.90	1.65	11.55	37.15	6.40	16.70	11.25	–	–
Minimum	10.30	1.65	7.80	31.80	6.40	10.95	11.25	–	–
Maximum	16.85	4.00	12.75	46.45	16.30	16.70	15.45	–	–
Mean	13.02	2.43	10.70	38.47	12.67	13.25	13.87	–	–
Std dev.	3.01	1.15	2.27	6.60	4.71	2.66	1.98	–	–

Heavy Metals Content in Unprocessed and Processed Cassava

Comparison of the metal contents in unprocessed cassava (at 9 months) and processed cassava at 12 months and at 18 months were carried out and presented in Tables 3.18, 3.19, and 3.20. It was observed that the unprocessed cassava had Cr values of 42.1 mg/kg (Kpean), 51.15 mgkg^{-1} (Oil location) and 57.20 mgkg^{-1} (Zaakpon). These values were found to have reduced after 12 months to 10.30 mgkg^{-1}, 16.85 mgkg^{-1} and 11.90 mgkg^{-1} respectively while at 18 months they were not detected. Co values of 8.55 mgkg^{-1}, 9.45 mgkg^{-1}, and 4.90 mgkg^{-1} were obtained from the unprocessed cassava from Kpean, oil location, and Zaakpon respectively. After 12 months, the values were found to have reduced to 1.65 mgkg^{-1}, 4.02 mgkg^{-1}, and 1.65 mgkg^{-1} respectively. Co was completely absent at 18 months. Mn concentrations were 18.05 mgkg^{-1}, 24.50 mgkg^{-1}, and 30.10 mgkg^{-1} for the unprocessed cassava from Kpean, oil location and Zaakpon farms respectively.

Table 3.20 Concentration of the metals (mgkg^{-1}) for processed cassava (garri) at 18 months

Farm	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Kpean	–	–	50.85	3.40	8.00	21.21	–	–	–
Oil location	–	–	102.30	4.90	9.10	22.15	–	–	–
Zaakpon	–	–	99.05	4.40	4.00	18.60	–	–	–
Minimum	–	–	50.85	3.40	4.00	18.60	–	–	–
Maximum	–	–	102.30	4.90	9.10	22.15	–	–	–
Mean	–	–	84.07	4.23	7.03	20.65	–	–	–
Std dev.	–	–	28.81	0.76	2.68	1.84	–	–	–

After 12 months the values decreased from between 38–52%. The values obtained were 7.80 mgkg^{-1}, 12.75 mgkg^{-1}, and 11.55 mgkg^{-1} respectively. However, at 18 months, the concentrations of Mn in all the cassava samples were found to be very high, 50.85 mgkg^{-1} for Kpean, 102.30 mgkg^{-1} for Oil location, and 99.05 mgkg^{-1} for Zaakpon. These values were higher than the values recorded in the corresponding soil samples indicating hyper accumulation in the crops. The unprocessed cassava had values for Fe concentrations that were higher than the processed cassava. These are 66.85 mgkg^{-1}, 62.85 mgkg^{-1}, and 52.30 mgkg^{-1}for Kpean, Oil location and Zaakpon while at 12 months the values reduced to 46.45 mgkg^{-1}, 31.80 mgkg^{-1}, and 37.15 mgkg^{-1} respectively. At 18 months, these values were lower by a factor of 20 to a factor of 12. The values obtained were 3.40 mgkg^{-1}, 4.90 mgkg^{-1}, and 4.40 mgkg^{-1} respectively. Values of Ni in the unprocessed cassava are 22.60 mgkg^{-1} (Kpean) and 15.55 mgkg^{-1} (Oil location and Zaakpon). After 12 months, the values obtained were 15.30 mgkg^{-1}, 16.30 mgkg^{-1}, and 6.40 mgkg^{-1} respectively. At 18 months, the processed cassava had 8.00 mgkg^{-1}, 9.10 mgkg^{-1}, and 4.00 mgkg^{-1}. Indicating that the levels of Fe and Ni were reducing as the crop stayed longer. Between the unprocessed and processed cassava at 12 months. No appreciable difference was observed in the concentrations of Zn. However, at 18 months the Zn concentrations doubled for the processed cassava samples. Cu concentrations for the unprocessed cassava harvested at 9 months from Kpean, oil location and Zaakpon farms were 13.55 mgkg^{-1}, 13.00 mgkg^{-1}, and 15.10 mgkg^{-1} respectively. For the processed cassava at 12 months, the concentrations were 14.90 mgkg^{-1}, 15.45 mgkg^{-1}, and 11.25 mgkg^{-1} respectively, whereas Cu was absent in the 18 months' samples. Raw cassava harvested after 9 months of planting had higher concentrations of the metals as presented in Table 3.18 while the processed cassava (garri) harvested at 9 months (Table 3.19) had values that were 4–5 times lower than the raw (unprocessed) cassava. However, the results are different for Zn where higher concentrations were obtained in the processed cassava (garri) as presented in Table 3.20. Cd and Pb, which were detected in the unprocessed cassava at 9 months, were not detected in the processed cassava at 12 and 18 months. Mn and Zn are the only metals that indicated hyper-accumulation in the processed cassava (garri) at 18 months after planting. For Fe and Ni, their concentrations reduced as the cassava stayed longer while Cr, Co, and Cu were completely absent at 18 months.

The absence of Cd and Pb in the processed garri after 12 and 18 months is good, as these metals have been identified as carcinogens.

Health Risk Index (HRI)/Dietary Intake Requirement (DIR)
HRI has been acknowledged as an extremely helpful indicator for assessing the health risk connected with the consumption of food crops polluted with heavy metals (USEPA 2003; Lui et al. 2005; Wang et al. 2005). If a crop's index is less than one, it is considered safe. The health risk impact assessment could not be carried out due to bureaucratic bottlenecks which did not enable the researchers have access to the adequate number of proximate consumers within the communities around these farms. However, a dietary intake requirement (DIR) assessment was done following a previous study by Kalagbor et al. (2015a). Results are presented in Tables 3.21a, 3.21b, 3.22a, 3.22b, 3.23a, and 3.23b.

$$\text{Using the equation DIR} = \frac{C_{\text{metal}} \times D_{\text{food intake}}}{B_{\text{average weight}}} \quad (3.3)$$

Table 3.21a Dietary Intake Rate (DIR), mg person^{-1} yr^{-1} for harvested samples from Kpean farm

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	143.80	29.20	61.65	228.33	77.19	33.99	46.28	5.46	74.46
Three-leaved yam	81.80	26.13	110.32	219.28	101.44	34.67	44.40	1.20	38.25
Water yam	133.38	23.06	46.11	214.67	28.86	56.02	46.28	2.56	19.64
White yam	164.29	41.67	50.55	196.74	149.94	44.06	62.51	1.20	62.33
Maize	79.84	14.03	59.28	97.86	37.62	79.96	39.44	1.81	–
Minimum	79.84	14.03	46.11	97.86	28.86	33.99	39.44	1.20	19.64
Maximum	164.29	41.67	110.32	228.33	149.94	79.96	62.51	5.46	74.46
Mean	120.62	26.82	65.58	191.38	79.01	49.74	47.78	2.45	48.67
Std dev.	38.00	10.05	25.80	53.53	49.41	19.11	8.69	1.78	24.52

Table 3.21b Dietary Intake Rate (DIR), mg person^{-1} day^{-1} for harvested samples from Kpean farm

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.39	0.08	0.17	0.63	0.21	0.09	0.13	0.01	0.20
Three-leaved yam	0.22	0.07	0.30	0.60	0.28	0.09	0.12	0.00	0.10
Water yam	0.37	0.06	0.13	0.59	0.08	0.15	0.13	0.01	0.05
White yam	0.45	0.11	0.14	0.54	0.41	0.12	0.17	0.00	0.17
Maize	0.22	0.04	0.16	0.27	0.10	0.22	0.11	0.00	–
Minimum	0.22	0.04	0.13	0.27	0.08	0.09	0.11	0.00	0.05
Maximum	0.45	0.11	0.30	0.63	0.41	0.22	0.17	0.01	0.20
Mean	0.33	0.07	0.18	0.52	0.22	0.14	0.13	0.01	0.13
Std dev.	0.10	0.03	0.07	0.15	0.14	0.05	0.02	0.00	0.07

Table 3.22a Dietary Intake Rate (DIR), mg person^{-1} yr^{-1} for harvested samples from oil location farm

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	174.71	32.28	83.68	214.67	53.11	35.52	44.40	1.20	38.25
Three-leaved yam	133.38	29.20	136.79	250.71	28.86	108.62	62.51	4.10	25.96
Water yam	133.38	23.06	52.77	210.23	53.11	50.89	66.09	1.20	25.96
White yam	144.14	32.28	48.33	219.28	101.44	39.79	51.58	1.20	62.33
Maize	101.86	18.51	60.85	116.98	32.66	73.31	32.78	1.81	–
Minimum	101.86	18.51	48.33	116.98	28.86	35.52	32.78	1.20	25.96
Maximum	174.71	32.28	136.79	250.71	101.44	108.62	66.09	4.10	62.33
Mean	137.49	27.06	76.49	202.37	53.84	61.63	51.47	1.90	38.13
Std dev.	26.14	6.09	36.36	50.32	28.89	30.07	13.55	1.26	17.15

Table 3.22b Dietary Intake Rate (DIR), mg person^{-1} day^{-1} for harvested samples from oil location farm

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.48	0.09	0.23	0.59	0.15	0.10	0.12	0.00	0.10
Three-leaved yam	0.37	0.08	0.37	0.69	0.08	0.30	0.17	0.01	0.07
Water yam	0.37	0.06	0.14	0.58	0.15	0.14	0.18	0.00	0.07
White yam	0.39	0.09	0.13	0.60	0.28	0.11	0.14	0.00	0.17
Maize	0.28	0.05	0.17	0.32	0.09	0.20	0.09	0.00	–
Minimum	0.28	0.05	0.13	0.32	0.08	0.10	0.09	0.00	0.07
Maximum	0.48	0.09	0.37	0.69	0.28	0.30	0.18	0.01	0.17
Mean	0.38	0.07	0.21	0.55	0.15	0.17	0.14	0.01	0.10
Std dev.	0.07	0.02	0.10	0.14	0.08	0.08	0.04	0.00	0.05

Table 3.23a Dietary Intake Rate (DIR), mg person^{-1}yr^{-1}for harvested samples from Zaakpon farm

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	195.37	16.74	102.81	178.64	53.11	40.65	51.58	1.20	25.96
Three-leaved yam	71.39	34.84	101.44	210.23	101.44	46.62	46.28	2.56	86.59
Water yam	133.38	23.06	50.55	228.33	101.27	82.32	71.39	1.20	38.25
White yam	174.71	35.52	61.65	255.32	102.13	44.06	58.92	4.10	74.46
Maize	109.11	25.16	81.29	132.95	20.44	91.94	31.45	0.85	–
Minimum	71.39	16.74	50.55	132.95	20.44	40.65	31.45	0.85	25.96
Maximum	195.37	35.52	102.81	255.32	102.13	91.94	71.39	4.10	86.59
Mean	136.79	27.06	79.55	201.09	75.68	61.12	51.92	1.98	56.31
Std dev.	13.93	2.56	8.28	9.08	10.04	11.15	3.22	0.38	8.44

Table 3.23b Dietary Intake Rate (DIR), mg person^{-1} day^{-1} for harvested samples from Zaakpon farm

Sample	Cr	Co	Mn	Fe	Ni	Zn	Cu	Cd	Pb
Cassava	0.54	0.05	0.28	0.49	0.15	0.11	0.14	0.00	0.07
Three-leaved yam	0.20	0.10	0.28	0.58	0.28	0.13	0.13	0.01	0.24
Water yam	0.37	0.06	0.14	0.63	0.28	0.23	0.20	0.00	0.10
White yam	0.48	0.10	0.17	0.70	0.28	0.12	0.16	0.01	0.20
Maize	0.30	0.07	0.22	0.36	0.06	0.25	0.09	0.00	–
Minimum	0.20	0.05	0.14	0.36	0.06	0.11	0.09	0.00	0.07
Maximum	0.54	0.10	0.28	0.70	0.28	0.25	0.20	0.01	0.24
Mean	0.37	0.07	0.22	0.55	0.21	0.17	0.14	0.01	0.15
Std dev.	0.14	0.02	0.06	0.13	0.10	0.07	0.04	0.00	0.08

where

C_{metal} denotes the concentration of heavy metals in the tuber/grain
$D_{\text{food intake}}$ is daily intake of tuber/grain (kg/person)
$B_{\text{average weight}}$ is the average adult body weight

According to Walpole et al. (2012), the average adult weighs 62 kilogrammes (132 pounds). Using Eq. (3.3), the authors in this study calculated a person's dietary intake rate (DIR) and used that information to estimate their body burden with heavy metals. According to Inter-special reseaux's report on staple food production and consumption, the yearly intake of tuber and grains is based on this figure (2010). Tuber and grain intake was estimated at 214 kg and 150 kg per person per year, respectively. Tables 3.21a, 3.22a, and 3.23a show the mg person^{-1} year^{-1} and mg person^{-1} day^{-1} DIR estimations for the three farms, respectively.

The amounts of metals in Kpean's cassava were relatively high, Ni (4.09 mgkg^{-1}), Cu (9.64 mgkg^{-1}), Fe (6.34 mgkg^{-1}), Pb (13.44 mgkg^{-1}), and Zn (0.22 mgkg^{-1}) when compared to FAO/WHO recommended values for crops. Researchers found higher quantities of Fe and Zn in the white yam and three-leaved yam samples collected from the Kaani farm and higher concentrations of Cu, Ni, and Pb in samples collected from Zaakpon. Many disorders affecting the cardiovascular, renal, neurological, or skeletal systems, as well as the nervous system, have been linked to elevated levels of heavy metals including lead and cadmium in diet (Jarup 2003; Steenland and Boffetta 2000; Radwan and Salam 2006). Carcinogens include cadmium, arsenic, and chromium (Trichopoulos 1997). From the DIR calculations, it is observed that the average daily intake of Fe from the tuberous crops is high (0.52–0.55 mgperson^{-1} day^{-1}), followed by Cr (0.33–0.38 mgperson^{-1} day^{-1}), Ni (0.15–0.22 mgperson^{-1} day^{-1}) Mn (0.18–0.22 mgperson^{-1} day^{-1}) Zn (0.14–0.17 mgperson^{-1} day^{-1}) Cu (0.14 mgperson^{-1} day^{-1}) and Pb (0.10–0.15 mgperson^{-1} day^{-1}). Co and Cd are in low concentrations of 0.07 mgperson^{-1} day^{-1} and 0.01 mgperson^{-1} day^{-1} respectively. Oti and Nwabue (2013) obtained values for Pb, Zn and Ni for white yams which were comparable to those obtained by Kalagbor et al. (2015b) and also in this study. The summary of the values of DIR from the three farms is presented in Table 3.24.

Table 3.24 Summary of DIR, mg person^{-1}/day^{-1} for the three farms

Metals	Range
Cr	0.33–0.38
Co	0–0.07
Mn	0.18–0.22
Fe	0.52–0.55
Ni	0.15–0.22
Zn	0.14–0.17
Cn	0.13–0.14
Cd	0–0.01
Pb	0.10–0.15

Health Implications of the Results from DIR

The biochemistry and physiology of lead, cadmium, and mercury in humans are unknown, according to research on these elements (Lenntech 2004). Because these metals bio-accumulate and have been classed as carcinogens, even low amounts of these metals in the diet can be detrimental.

There are four oxidation states for Cr. There are, however, two that are more commonly found: Cr (III) and Cr (VI), both of which are crucial for normal sugar and fat metabolism. As Cr (VI) is not advantageous to man, it is more common in the environment. The liver, kidneys, spleen, and bones can all be damaged by high quantities of it (Dayan and Paine 2001).

Vitamin B12, which contains Co, is necessary for the production of red blood cells. Small amounts are critical. A buildup of red blood cells may occur if you eat too much of this element. It has mutagenic and carcinogenic effects at high concentrations.

The hepatorenal activities of Mn are promoted. The pituitary gland relies on it for proper operation. However, when present in high concentration, it can cause brain and nerve damage, as well as other health issues such as amnesia.

Anaemia is caused by a deficiency in the mineral ferrous, which is required by nearly every living organism. Hemoglobin is made possible by iron, which is a component of iron oxide. Fe is quickly absorbed in the intestines. Iron-overload is a term used to describe when the body has an abnormally high level of iron (hemochromatosis). Acute conjunctivitis, choroiditis, retinitis, or siderosis may result (Karadede-Akin and Unlu 2007).

When Ni is present in trace amounts, several enzymes are activated. In addition to Fe, it has a role in fat metabolism and serves as a biocatalyst. It is thought to be carcinogenic at larger doses, and it can also cause skin irritation, heart problems, and liver problems.

As a micronutrient for optimal health, Cu is a metal that can be found in the environment and accumulates in plants and animals. Toxic symptoms, such as irritability of the nose and eyes, nausea, diarrhoea, and stomach cramps, can occur when the concentration is too high. It is also possible that it contributes to cancers of the liver and the brain (Ellis and Salt 2003). Copper overexposure can be dangerous for people with Wilson's disease (Xian and Wespe 2011).

Even at low concentrations, cadmium is hazardous. Lung illness is a result of Cd exposure. Hepatobiliary and hepatic systems are among those targeted by this drug (Purves 1999). Osteomalacia, osteoporosis, and spontaneous fractures are all linked to it. Long-term exposure causes renal failure, prostate and ovarian malignancies, among other health issues (Radwan and Salam 2006).

When used orally, zinc is regarded to be largely non-toxic. Vomiting, bloody urine, liver failure, renal failure, and anaemia have been recorded as symptoms of Zn toxicosis (Fosmire 1990). It has been found to cause the same symptoms as lead poisoning, making a diagnosis of lead poisoning an easy one to make.

Any sort of Pb is harmful. It is a toxicant that can be found in metallic Pb and inorganic irons, and it is found everywhere (Egendorf et al. 2020). Lead is a carcinogen and can cause birth defects in humans. Hemoglobin synthesis is inhibited, the kidneys, joints, reproductive systems, cardiovascular systems, and the central and peripheral neurological systems are permanently damaged by Pb poisoning (Ogwuegbu and Muhanga 2005). Ca and Zn deficiency increase the body's absorption of lead. When consumed, heavy metals undergo oxidation in the stomach's acidic environment, where they form chemical interactions with biomolecules like proteins and enzymes, interfering with the body's normal biochemistry and metabolism. According to Ogumegbu and Ijioma, the poisoned metal replaces the hydrogen atoms or metal groups in metabolic processes, inhibiting the enzyme's function (2003). Nirmal et al. (2007) found that the concentration of heavy metals in crop plants was higher than that in the soil. Since the uptake and accumulation rates are high, this could be a factor. In soil samples, heavy metals have been found in higher concentrations than have been found in cassava (Nkwocha et al. 2011; Idodo-Umeh and Ogbeibu 2010; Okoye and Okwute 2014). This study also found that cassava has this potential.

3.4 Conclusions

The majority of the data analysis was based on AAS results. The XRF analysis was used for comparison purposes and proved to be a beneficial technique in this study. The soil from the oil location had the highest concentration values for all metals found in this investigation, according to the AAS and XRF data. Fe > Zn > Ni > Mn > Pb is the order of metal concentrations. There is heavy metal contamination in these soils based on the pollution load index for Fe and Ni. For the tuberous crops, PCF indices for Mn, Ni, and Pb were high, whereas Maize had the highest PCF value for Zn from all three farms. The highest concentration of metals was found in Yam, followed by Cassava, three-leaved yam, then water yam, and finally maize, in that order. This shows that the intake of Fe from these tuberous crops is unacceptable, White yam consumption must be limited to prevent the buildup of some of these heavy metals to dangerous levels on a daily basis. After

18 months of cultivation, the Fe and Ni content of processed cassava (garri) was decreased. Mn and Zn concentrations, on the other hand, were higher. There were no metals found in the 18-month-old processed cassava (garri). There is need for bioremediation of oil-impacted soils in the farmlands in this local government area to reduce the levels of these heavy metals. Further studies should be carried out to ascertain the levels of other heavy metals not included in this study.

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Chapter 4
The Role of Food in the Health Management of Geriatrics

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4.1 Introduction

Naturally, ageing is associated with growing health challenges; many chronic and non-infectious diseases are more likely to emerge with age. Nevertheless, the current nutritional status and healthcare system are unprepared and/or overwhelmed by the demand for this proposed surge in the ageing population (Tucker and Buranapln 2011). The ageing population (60 years and above) was estimated to be 962 million in 2017; by 2050 it is projected to be about 2.1 billion of the total population (Nations. 2017). In 2017, Africa recorded about 68.7 million elderly, which is expected to increase to approximately 225.8 million by 2050. Still, Asia has the highest record of geriatrics with about 549.2 million and a projection of about 1.2 billion by 2050 (Nations 2017). Albeit, the life expectancy of the older population in Sub-Saharan Africa (SSA) has experienced the largest increase from 49.1 years in 1990–1995 to 60.5 years in 2015–2020 (11.4 years); it is projected to face a further gain of 7.6 years between 2015–2020 and 2045–2050 (Nations 2019). In SSA, about 73% of the ageing population are farmers, which is their primary source of income (Heide-Ottosen 2014). This is significant in achieving Goal 3 of Sustainable Development goals 2020–2030: "Ensure healthy lives and promote wellbeing for all ages".

Unlike other vulnerable groups, older people do not enjoy the luxury of attention. Even though they contribute the most to food production, many are food insecure. They do not eat appropriately to meet their required RDA; consequently, this exposes them to various chronic diseases that could have been prevented (Fernandes

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et al. 2018). Chronic diseases (e.g., arthritis, diabetes, cardiovascular diseases) occur at increasing rates and can be prevented and managed. It affects daily human activities thus, resulting in many discomforts (Institute of Medicine 2010). Most of the medications prescribed for these chronic diseases can cause adverse effects, which is one reason why the roles that can be played by nutritious diets should be advocated. Studies have shown that ageing comes with several challenges: malnutrition and inadequate healthy diets. Thus, the importance of good nutrition in the elderly cannot be overemphasized (Leslie and Hankey 2015).

Subsequently, foods rich in dietary fibre, omega-3-fatty acids, vitamins, and minerals have been considered essential for the older people's diet. This will promote digestion, cognitive function, a healthy weight, bowel movement, a good sleeping pattern, bone health, relaxed mind, and lowered cholesterol levels (Barber et al. 2020; Sheppard and Cheatham 2018; Clifford and Bellows 2015). Studies by Saha et al. (2021) have provided a guide to promote healthy nutrition in the elderly.

The objective of this review concentrates on the role food and nutrition play in managing diseases of the elderly. It also provides solutions to prevent these diseases by encouraging nutritious diets and precautions that should be taken early in life.

4.2 Food Production Statistics in Africa

The underperformance of food production in Africa went as far back as the colonial period. During this time, African countries focused on producing cash crops. Food crop production was done at the subsistence level and was not promoted. After independence, agriculture was still underfunded because it was termed less productive compared to cash crops and other mineral resources (e.g., crude oil). The millennium years saw specific strategies to increase agricultural yield, which involved education, technical expertise, and modern management practices (IFPRI 2016).

These strategies led to optimizing production of certain crops in various regions of Africa, as noted in Africa (2019):

> In West Africa, roots and tubers account for 46% of the region's total production, followed by fruits and vegetables (19%), cereals (19%), cash crops (6%), oilseeds (5%) and pulses (3%). In Central Africa, oilseeds account for 50% of the region's total output, followed by cash crops (14%), cereals (13%), fruits and vegetables (10%), roots and tubers (7%), and pulses (5%). In East Africa, roots and tubers account for 32% of the total output, followed by cereals (31%), fruits and vegetables (18%), cash crops (10%), pulses (5%), and oilseeds (4%). In South Africa, fruits and vegetables continue to have by far the biggest share of production, with 52% of the total, followed distantly by cereals (26%), cash crops (8%), roots and tubers (7%), oilseeds (5%) and pulses (0.4%).

The largest share of livestock production in SSA countries is poultry (Africa 2019):

> In West Africa, poultry represents the largest production with 27%, followed by sheep and goat (24%), beef (23%), dairy (11%), and pork (9%). In Central Africa, the largest output also comes from poultry (46%), with dairy (10%), beef (6%), sheep and goats (2%), and pork (1%) coming next. In East Africa, dairy accounts for the biggest production (45%),

followed by beef (18%), pork (16%), poultry (12%), and sheep and goat (6%). Lastly, in Southern Africa, poultry is coming first with a share of 45%, followed by beef (26%), dairy (14%), sheep and goat (8%), and pork (5%) (Africa 2019).

The fishery and aquaculture sector is still very much underexploited, even though its production accounted for 4% of the world's total output.

Globally, there has been a change in the consumption of starchy foods, accounting for only half of the energy supply. Starchy food consumption in SSA, however, is still very high, accounting for two-thirds of the total energy supply (FAO 2017), associated with the increased production output of cereal, root, and tubers. The average cereal consumption in SSA is about 1075 kcal/capital/day (Chauvin et al. 2012). The average animal protein consumption continuously increases in other world regions, reaching 32 g per day. The supply of animal protein in Sub-Saharan Africa is about 13 g per day except for South Africa, which has less than 1% of the total calories consumed (Chauvin et al. 2012; FAO 2017). This low figure contributes to the fish export trade; many fish catches (e.g., marine, inland, and aquaculture) are exported. Vegetable consumption is not popular in SSA and has decreased for the past 40 years, accounting for 1.185 of the total caloric supply (Chauvin et al. 2012).

4.2.1 The Increase in Age of Africa's Population

In Africa, older people contribute the most to food production but can also be at risk of food insecurity. Elderly nutrition and food security are not given sufficient attention and priority like other vulnerable groups (e.g., children, pregnant and lactating women). Older people are a significant proportion of the world's population. Currently, 1.05 billion people are estimated to be aged 60 or older, accounting for 13.6% of the world's population; by 2050, this figure will double (Nations 2019). All regions around the world will experience an increase in the older population.

Africa's ageing population is projected to rise by 216%, with an expected growth of 74.4 million in 2020 to 235.1 million in 2050 (He et al. 2020). According to future projections, only Africa will experience a steady increase every 10 years. West Africa has the highest number of older people living in there in 2020 (20.4 million). This figure is low compared to South Africa, which has the lowest population in Africa and yet 8.9% of its population is elderly compared to 5.1% in West Africa. Eastern Africa is estimated to experience the highest increase by 2050 (69.4 million). Nigeria has the highest older population in Africa (10 million) and coming in second, third, and fourth are Egypt (7 million), Ethiopia (5 million), and South Africa (5 million), respectively (He et al. 2020).

4.3 Epidemiology of Diseases Affecting the Ageing Population

'Ageing' refers to the physiological changes in the human body from adulthood attainment to death. The ageing process brings about observable physiological, biological, psychological, and behavioural changes. Yet, some of these changes may not be obvious.

The ageing process defers from an individual, and it could be normal, pathological, or successful ageing. Successful ageing involves increased mental and functional ability, energetic well-being, and probable disease prospects (Urtamo et al. 2019). Likewise, physiological parameters or a set of parameters (e.g., people with periodontium, who age successfully), will have an intact dentition with limited attachment loss and minimal limitations on function (Lamster et al. 2016; Urtamo et al. 2019).

Disease is represented by mild, moderate, or severe conditions. Disability would be indicated by disease-related functional decrements in the periodontium, including tooth mobility and sensitivity that impairs function, appearance, and social interactions. Age could be related to a decreased prevalence of disease (e.g., autoimmune diseases) or an increased incidence and severity of the disease (e.g., periodontitis), which increases with age.

Various diseases (e.g., diabetes, hypertension, cancer, Alzheimer's, osteoporosis, arthritis, cardiovascular disease, and so on) affect the ageing population (Amarya et al. 2014). Diabetes has affected about 136 million of the elderly, and it is projected to increase to approximately 276.2 million by 2045. India, China, and the United States have the highest diabetes prevalence among the aged (Sinclair et al. 2020). An increase in high blood pressure indicates hypertension in the elderly, which is the leading cause of death among them (Bosu et al. 2019). According to WHO (2014), Africa has the highest prevalence of hypertension. Hypertension risk factors (e.g., high salt intake, high fat intake, smoking, and lack of physical activity) have been the cause for an increase in its prevalence, especially in developing countries.

Consequently, about 50 million people have dementia, a major mental health disease of the aged (WHO 2020). This disease renders the elderly dependent on a caregiver, and it is associated with forgetfulness, walking difficulty, and behavioural changes. Furthermore, osteoarthritis is the most common form of arthritis in the aged. It has global statistics of 9.6% in men and about 18% in women (French et al. 2016).

In developed countries, the percentage of over 65 years of age increases in absolute numbers. Metrics from the Centers for Disease Control's Morbidity and Mortality Weekly Report show a doubling population over 65 years of age in 30 years. The population percentage of 65 years and older will increase from 12.4–19.6% in the US from 2000–2030. In Europe, 12.6–20.3%, from 6–12% in Asia, from 5.5–11.6% in Latin America and the Caribbean, and 2.9–3.7% in Africa. This transition comes with previously unseen public health challenges. For example, 80% of elderly individuals have at least one chronic condition, and 50% have two. Apart from increased morbidity, mortality, and healthcare costs, these conditions may sometimes lead to severe disability.

Ageing is associated with low-grade inflammatory phenotype in mammals called 'inflammageing'. The autophagic capacity product impairs so-called 'housekeeping activities' (i.e., activities of daily living) in cells, resulting in protein aggregation, mitochondrial dysfunction, and oxidative stress. The systemic inflammation associated with inflammageing has been thought to exacerbate vascular pathology and cause atherosclerosis, increased secretion of cortisol resulting in insulin resistance in muscles, and bone resorption (Salminen et al. 2012).

A human study showed that the generation of neutrophil extracellular traps was lower in older individuals. According to Hazeldine et al. (2014), altered formation of neutrophil extracellular traps is not associated with an increased incidence of periodontitis in older people. Malnutrition also has been linked to immune deficiencies in the elderly because protein–calorie malnutrition and zinc deficiency are associated with immune cell function deficiencies (Hazeldine et al. 2014).

Ageing has been associated with periodontitis and tooth loss in various studies. There is less fibrous and cellular content in an aged person's periodontium than in a young individuals. Well-designed studies in older people have shown that periodontitis is a multifactorial disease. Its extent and severity affect only a limited proportion of the ageing population (Renvert et al. 2013). A compromised or debilitating medical condition, rather than direct physiological ageing, may be an essential determinant of periodontitis in many elderly. Additionally, periodontitis in the aged might serve to worsen systemic health. The effects of systemic diseases and medications, psychological effects, and decreased interest in or ability to perform oral hygiene practices are thought to result in periodontal diseases, and ultimately in tooth loss, in aged individuals (Azzolino et al. 2019; Renvert et al. 2013).

Ageing is linked with an increased prevalence of systemic diseases (notably arthritis, cardiovascular diseases, and stroke). These conditions, coupled with multiple pathologies and multiple medications, are associated with a decline in physiological function (e.g., lack of manual dexterity, prone to injuries or injury-related, and reduced salivary flow). These can contribute to the development and progression of oral diseases because of the neglect of oral hygiene and bacterial plaque accumulation (Alrahabi 2019).

Aged individuals also are less likely to access dental treatment. Such persons with the highest disease prevalence are the least likely to have access to care (Nazir 2017; Renvert et al. 2013). This, in turn, can have periodontal, dental, and medical consequences. Furthermore, immune senescence in the elderly can contribute to the proliferation of bacteria and can partly explain the role of poor dental health in aspiration pneumonia. Because dental procedures can cause transient bacteremia associated with cardiovascular disorders from direct bacterial actions or indirect immune-cell-mediated vascular pathology, it is essential to establish and maintain good oral health in older individuals (Griffin et al. 2012; Nazir 2017).

Geriatrics have the possibility of having chronic diseases (e.g., cardiovascular disease, diabetes and bone-related diseases) as they age. These diseases affect the quality of their lives, put them on daily medications, and may deprive them of enjoying daily activities. In addition, most of these medications can adversely affect their oral health, causing hyposalivation. Some other side effects could result in hypersensitivity, bleeding disorders, and tissue overgrowth (Jaul and Barron 2017).

4.4 Role of Dietary Fibre and Omega 3 Fatty Acid on the Health Management of Geriatrics

4.4.1 Dietary Fibre

Dietary fibres are indigestible soluble and insoluble polysaccharide carbohydrates of vegetable origin that cannot be digested and absorbed in the small intestine but are completely or partly fermented in the large intestine. This includes waxes, lignin, and polysaccharides (e.g., cellulose and pectin). Some fibre can be fermented in the large intestine by gut bacteria, producing short-chain fatty acids and gases (e.g., methane, hydrogen, and carbon dioxide). The fatty acids are absorbed into the bloodstream and provide small energy.

Dietary fibre consumption aids in managing some metabolic conditions, including diabetes, hypercholesterolemia, hypertriglyceridemia, obesity, hypertension (Brown et al. 1999; Post et al. 2012; Brauchla et al. 2012). A maximum of 40 g per day of dietary fibre intake can decrease total and LDL cholesterol and triglyceride levels, corresponding to reduced blood glucose and reducing the risk of type 2 diabetes (Mogos et al. 2017). Exceeding this limit, however, could lead to digestive intolerance and dyspeptic disorders (e.g., flatulence, abdominal pain, nausea, heartburn, burping, bloating (Mogos et al. 2017).

Therefore, a total daily intake of 30 g is recommended and considered an indicator of a healthy lifestyle (Kaline et al. 2007). In addition, a meal comprised of fruits and vegetables, wholegrain cereals (e.g., grains of any cereal that contains bran, germ and endosperm), and legumes provide bulkiness and satiety. Consequently, it slows down digestion and nutrient absorption, preventing weight gain, type 2 diabetes, and other chronic metabolic diseases.

Insoluble fibre acts as a bulking (laxative) agent and helps prevent constipation. Therefore, increased water consumption is essential when there is increased fibre consumption. On the other hand, eating a diet low in fibre is associated with diverticulitis, where the bowel wall becomes inflamed and damaged, and bowel (colorectal cancer) cancer. Studies have shown the protective effect of eating a diet rich in dietary fibre on diverticulitis and colorectal cancer (Aune et al. 2020; Kunzmann et al. 2015). Insoluble dietary fibre includes cellulose, hemicellulose, and lignin. Wholegrain cereals (e.g., oatmeal, couscous, quinoa, wheat, barley and whole meal bread) are good sources of fibre.

Soluble fibre eaten in substantial amounts can help reduce blood cholesterol levels. Diets rich in soluble fibre (e.g., fruits and grains, and particular oats) have been shown to reduce low-density lipoprotein (LDL) cholesterol (Soliman 2019). In addition, some evidence suggests that a high dietary fibre intake reduces the risk of developing type 2 diabetes (McRae 2018). Soluble dietary fibre includes beta-glucans, pectins, gums, mucilages, and hemicelluloses. Oats, fruit, vegetables, and pulses (e.g., beans, lentils, and chickpeas) are good sources.

Dietary fibre has been shown to improve glycemic control and has a vital role in managing diabetes (Reynolds et al. 2020; Fujii et al. 2013; Weickert and Pfeiffer 2018). Foods high in fibre tend to have a high volume and low energy density. These foods may help reduce hunger, promote a sense of fullness, and control energy balance. Increased fibre intake brings about a reduction in intake of other food and fat. A high fibre intake may be a protective factor against overweight and obesity.

The DRV for fibre is 18 g for adults. A diet rich in fibre is usually lower in fat and contains more starchy foods, fruits, and vegetables. High intakes of dietary fibre may reduce the absorption of some minerals from food because the fibre binds them in insoluble complexes. Fermentation of fibre in the large intestine, however, can release some of the bound minerals (e.g., calcium) to be absorbed. The number of vitamins and minerals lost through eating a diet rich in fibre is not likely to be significant unless the diet is already poor. The health risks of a low-fibre diet are potentially much greater than those of a very high-fibre diet.

Dietary fibre refers to substances in plant foods that human digestive enzymes cannot completely break down. This includes waxes, lignin, and polysaccharides (e.g., cellulose and pectin). Some fibre, however, can be fermented in the large intestine by gut bacteria, producing short-chain fatty acids and gases (e.g., methane, hydrogen, and carbon dioxide). The fatty acids are absorbed into the bloodstream and provide small energy.

Fibres can be described as soluble and insoluble according to their solubility in water. Insoluble dietary fibre includes cellulose, hemicellulose, and lignin. Wholegrain cereals and whole meal bread are good sources. Soluble dietary fibre includes beta-glucans, pectins, gums, mucilages, and hemicelluloses. Oats, fruit, vegetables, and pulses (e.g., beans, lentils, and chickpeas) are good sources (Table 4.1).

4.4.2 Omega 3 Fatty Acids

Fish is an excellent source of omega 3 fatty acids. Therefore, its addition to the diet of older people is encouraged. Albeit. there are inconsistent reports about its effectiveness in the management of diabetes. Some studies revealed no effect of omega 3 fatty acid in the management of diabetes, and others showed a decrease in the chance of developing diabetes; still others reported it increases the risk of type 2 diabetes (Djoussé et al. 2011; Villegas et al. 2011). The inconsistency in the result

Table 4.1 Examples of Fibre and Food Source Components

Fibre Components	Description	Food Sources
Cellulose	Polysaccharides up to 10,000 glucose units are arranged linearly.	Grains, vegetables, fruits, nuts, cereal bran.
Hemicellulose	Polysaccharides containing sugars other than glucose.	Cereal grains, vegetables, fruit, legumes, and nuts.
Lignin	Non-carbohydrate component associated with plant walls.	Woody foods e.g., celery and outer layers of cereal grains.
Beta-glucans	Glucose polymers have a branched structure (unlike cellulose).	Mainly found in the cell wall of oats and barley.
Pectins	Non-starch polysaccharides (NSP) are common to all cell walls.	Fruits, vegetables, legumes, nuts, and potatoes.
Gums and mucilage	NSPs help hold plant cell walls together.	Gums: seaweed extract. Mucilage: pysillium seeds.
Resistant starch	The gut does not absorb starch and products of starch digestion.	Legumes
Oligosaccharides	Short-chain carbohydrates of 3–9 monomers. Fructo- and galactooligosaccharides	Onions, chicory, Jerusalem artichokes
Micro components (waxes, cutin, and suberin)	Micro components of the plant structures.	Cereal grains

Source: British Nutrition Foundation (2018).

could be because of chemical contaminants in marine fish (Folorunso and Oguntibeju 2013). Thus, plant-based oil with omega 3 (e.g., from walnuts, flaxseeds, chia seed, algae, and seaweed), has better prospects for managing diabetes in the elderly (Villegas et al. 2011).

Omega 3 fatty acid influences muscle contraction, which depends on the eicosanoid formed; it could contract or expand muscle. These are involved in blood clotting, constriction and dilation of blood vessels, and inflammatory responses. Therefore, they play a role in managing cardiovascular disease by lowering thrombosis through platelet and blood clotting reduction, reducing triglyceride levels in the blood, stabilizing the heartbeat, reducing the risk of fatal cardiac arrhythmia, and lowering high blood pressure (Upadhyay 2015).

Eicosanoids produced from omega 3 fatty acids are less potent and more favourable in reducing platelet aggregation and inflammatory responses; therefore, the balance of omega 3 and omega 6 is essential. The Food Standard Agency (FSA) advises eating a third of a portion of oily fish per week. Higher amounts are needed. at least 1.5 g/day of omega 3 fatty acid, for those with cardiovascular disease; that is, 2–3 portions of oily fish per week.

4.5 Role of Diet in the Ageing Population's Health Management

There is a high demand for other macro- and micro-nutrients for the elderly. The required energy goes down to maintain organ systems with decreasing functionality (Martyn et al. 1996). Vascular diseases and similar chronic diseases are the principal cause of death among older people (Ruan et al. 2018). The prevention and management of these diseases are possible with a nutritious diet. Household income level, however, influences dietary intake choices.

The low-income older person suffers malnutrition among other chronic diseases arising from it. Food transitioning from nourishing foods (i.e., high in fibre, low in fat) to processed foods (i.e., low in fibre, high in fat and sugar) is the crucial problem contributing to high rates of chronic diseases in SSA's middle and upper economic class . Low productivity of certain food crops, low accessibility, food transition, and increasing ageing population will increase chronic diseases. Hence, it is necessary to prioritise their nutrition, food security, and health.

Good nutrition is essential in supporting older people with a weakened immune system and overall well-being. Many older people live a sedentary lifestyle, making burning calories more challenging. Higher energy intake increases the risk of age-related diseases. Studies in the past have shown the correlation between specific diets and the development of age-related diseases, and many recent pieces of evidence emerging confirm this relationship (Ramos-Molina et al. 2019; Tan and Norhaizan 2019).

Food components (e.g., saturated fat, salt, sugar, calcium, folate, vitamins, micronutrients, and meats and vegetables) influence the development of certain diseases (Amarya et al. 2014; Lock et al. 2005; Pereira et al. 2004; Tucker et al. 2005). For example, high intake of sugar-sweetened beverages has been associated with type 2 diabetes, obesity, and metabolic syndrome. Sugar-sweetened beverages include soft drinks and soda, fruit juice/punch, sweetened iced tea, sweetened coffee drinks, sports drinks, and energy/vitamin water drinks. Likewise, the intake of a specific diet has been proven helpful in managing chronic diseases.

4.5.1 Obesity

Obesity globally affects all age groups, although common in the elderly, and it poses many risks to their health and well-being. One of the causes of obesity in the elderly is a sedentary lifestyle owing to reduced movement and physical activity. About 33.6% of women and 37.1% of men over 60 years of age are obese (Malenfant and Batsis 2019). It is a non-communicable disease that offsets the emergence of other health comorbidities.

Consequently, energy-dense foods with poor nutrient quality may contribute to greater obesity in some food-insecure older populations (Tucker and Buranapln

2011). The dietary approach to obesity requires consuming a low carbohydrate diet, a low saturated and trans-fat diet, a more fibre-rich diet, and a protein-rich diet. For example, studies by Noratto et al. (2015) showed that consumption of peach and plum juice protected against obesity and its comorbidities (e.g., cardiovascular disease) caused by the polyphenols present in them.

Recent research illustrates that protein adequacy is critical for maintaining functional status with age. Therefore, it is important for food consumed by older people to be rich in protein because ageing has been linked with a steady loss of muscle mass (i.e., sarcopenic obesity) (Forsen et al. 1999). Sarcopenic obesity is a progressive loss of muscle mass, reduced lean body mass, and excess fat mass accumulation. It is more prevalent in an older population (Volpe et al. 2016). This weight loss and dieting have been proclaimed harmful to the elderly (Dey et al. 2001; Flicker et al. 2010; Volpe et al. 2016).

These studies reported that BMI and mortality risk is not directly proportional, adding that low BMI and weight loss are risk factors for mortality in the elderly. Older people who are overweight with 25.0–24.9 BMI have a low mortality risk when compared with older people with normal BMI (18.5–24.9), obese (≥30), and underweight (˂18). At the same time, obesity makes direct and powerful contributions to the risk of chronic diseases such as coronary heart disease, stroke, and cancers of the oesophagus, endometrium, breast, prostate, kidney, and colon (Must et al. 1999; Field et al. 2002; Tucker and Buranapln 2011).

Therefore, it is essential to focus on preventing sarcopenic obesity in the elderly by encouraging healthy body weight by avoiding excess fat storage and adopting a proper diet. According to Goisser et al. (2015)) and Volpe et al. (2016), lean body mass and bone mass of the older population can be conserved through a meal plan consisting of low-fat, high-quality protein (e.g., lean meat, legumes, low-fat dairy, and protein supplementation), micronutrients (e.g., calcium, vitamin D, vitamin $B_{12,}$ iron, and zinc).

4.5.2 Diabetes Mellitus

About 19 million adults were currently living with diabetes in the SSA region in 2019. The figure is estimated to increase to 47 million by 2045 (IDF 2019). Diabetes mellitus is the abnormal metabolic response to glucose resulting in hyperglycemia because of insufficient insulin secretion or a failure to respond to insulin. When digested food enters the bloodstream, insulin moves glucose out of the blood into cells, broken down into energy controlled by insulin, a hormone produced in the pancreas. Diabetes is caused when the body cannot break down glucose into energy. It could be diagnosed through either a random venous plasma glucose concentration ≥11.1 mmol/l, a fasting plasma glucose concentration ≥7.0 mmol/l, or a 2-hour plasma glucose concentration ≥11.1 mmol/l 2 hours after 75 g glucose in an oral glucose tolerance test (Florkowski 2013). Diabetes differs in gender, ethnic group, diet, and genetic predisposition. It increases with age and affects men more than women.

Diabetes is a severe disease, and it affects many older adults. It can be adequately managed with the consumption of specific foods directly connected with food metabolism. The American Diabetes Association endorses specific diets through Medical Nutrition Therapy (MNT) in the management of diabetes. The consumption of fibre-rich foods has shown positive results in decreasing the glycaemic index of foods and preventing the shooting of blood glucose and HbA1c levels. MNT offers guidelines that ensure an adequate amount of fibre and micronutrients are consumed with starch by carefully selecting vegetables, fruits, and grains (Association 2002). Low glycaemic index foods (e.g., soya beans, apple, grapefruits, groundnuts, increased intake of vegetables, legumes, and wholegrain) should be consumed more with crucial emphasis on the total amount of carbohydrate in terms of energy intake (Folorunso and Oguntibeju 2013; Kelly 2003).

Fish is an excellent source of omega 3 fatty acids. Therefore, its addition to the diet of older people is being encouraged. Plant-based fish oil with omega 3 has better prospects in managing diabetes in the elderly (Villegas et al. 2011). Likewise, older people with diabetes should avoid high salt intake, saturated fat, and fried foods. The consumption of high-fat foods, especially food high in saturated fat, has been linked with insulin resistance (Folorunso and Oguntibeju 2013). The management of diabetes is crucial as it could lead to serious health problems (e.g., heart disease, stroke, kidney disease, eye problems, and nerve damage) that may lead to amputation. In addition, people with type 2 diabetes may be at greater risk for cancer and Alzheimer's disease (Li et al. 2015).

Fruit and vegetables should not be avoided as they are low in calories and help prevent stroke, heart disease, high blood pressure, and some cancers. People with diabetes are more at risk of developing these. Starchy foods (e.g., potatoes, rice, bread, pasta, and plantain) contain carbohydrates. Some starchy foods raise blood glucose levels quickly, making diabetes management difficult. These foods have what is called a high glycaemic index (GI). Some starchy foods affect blood glucose levels more slowly. These foods are called low glycaemic index (e.g., wholegrain bread, whole-wheat pasta, basmati, brown or wild rice).

Diet should be based on healthy eating guidelines, but weight loss is a priority for those who are overweight. There is a need to monitor energy intake as excess energy increases blood glucose and insulin demand. Excess body fat increases insulin resistance, and central obesity alters the lipid profile. Protein intake should not exceed 1 g/kg body weight. This is linked with diabetic nephropathy and those with this should be discouraged from following high protein diets. Carbohydrate intake should make up 45–60% of energy intake. Soluble fibre can help control blood glucose and lower cholesterol. Insoluble fibre has no direct effect but increases satiety, and rich sources tend to be low in fat.

4.5.3 Cardiovascular Disease

The most typical cause of disease in the elderly in Africa is cardiovascular diseases and stroke. Circulatory conditions were the leading identified health problems in elderly patients (Akinyemi et al. 2014; Allain et al. 2017; WHO 2018). Diets that restrict cholesterol and trans fatty acid intake have been shown to reduce CVD in human and animal studies (Chahoud et al. 2004). Antioxidant consumption (e.g., isoflavones, flavonoids, and polyphenols) has been shown to reduce CVD risk (Everitt et al. 2006; Gaziano 2004). Antioxidants food sources include: Vitamin C (e.g., citrus fruits and juices, berries, dark green vegetables, red and yellow peppers, tomatoes juice, pineapple, cantaloupe, mangos, papaya, guava), Vitamin E (e.g., whole grain, sweet potato, legumes), vegetable oil (e.g., olive, soybean, corn, and cottonseed), selenium (e.g., brewer's yeast, oatmeal, brown rice, chicken, garlic onions, seafood), beta-carotene (e.g., variety of dark orange, red, yellow and green vegetables), and fruits (e.g., spinach, carrot, broccoli). Studies have also shown the inverse relationship between the consumption of dietary fibre (wholegrain) and the risk of coronary heart disease (Anderson 2000; Erkkilä and Lichtenstein 2006). Plant food crops containing insoluble fibres (e.g., wholegrain cereals, fruits, and vegetables) have reduced CVD risk (Erkkilä and Lichtenstein 2006).

Fermented dairy foods (e.g., yoghurt and cheese) have been investigated to lower heart disease risk (Tapsell 2015). In addition, when consumed consistently, functional foods (e.g., oats, nuts, flaxseed, grapes, soya beans, and garlic) may lower CVD risk (Hasler et al. 2000). Furthermore, the Mediterranean diet rich in fruits and vegetables has been linked to reducing myocardial infarction; thus, the need to consume adequate fruits and vegetables cannot be overemphasised (Hu 2003). Fruits with high polyphenol content are berries, apples, dark grapes, cherries, and dark plums. Vegetables with high polyphenol content are rhubarb red cabbage. In addition, whole grains (e.g., rye, and wheat bran) had high polyphenol concentrations. At the same time, beverages (e.g., coffee, and cocoa powder) were high in phenolic acids (Ovaskainen et al. 2008).

4.5.4 Diet and Cancer

It is estimated that a third of cancer is linked to diet. There is a problem in establishing a link as diet is complex as reliance on one food group often lacks another. Cancer can take years to develop, and at what stage does diet have an influence?

4.5.4.1 Causes of Cancer

Body Fatness

Body fatness can increase cell proliferation, increase cell differentiation, inhibit apoptosis, and increase angiogenesis. In addition, adipose tissue increases inflammatory responses, the level of circulating oestrogen (breast and endometrium), reduces insulin sensitivity, increasing insulin secretion and growth-like factors.

Lack of Physical Activity

Physical activity reduces weight gain and body fat as a sedentary lifestyle associated with snacking on high-energy foods. Improved hormonal profile, less insulin resistance, less oestrogen, increased immunity, and reduced transit time through the colon.

Other causes of cancer include infection (hepatitis B, HPV), excessive drinking of alcohol, smoking, radiation exposure, exposure to chemicals, environmental pollutants, and genetic factors (Saini et al. 2020; Danaei et al. 2005).

4.5.4.2 Diet's Role in the Management of Cancer Among the Ageing Population

Diet can play a preventative or a causative role. It may provide a source of precursors of carcinogens; contain nutrients that affect the formation, transport, deactivation, or excretion of carcinogens; contain nutrients that can be protective by promoting the bodies' resistance; and play a role in the initiation, the promotion, and the progression of cancer (Koriech 1994). Consuming foods rich in fibres and bioactive compounds found in most fruits and vegetables (e.g., green leafy vegetables, garlic, onions, and carrots) have been investigated to protect against cancer. Furthermore, foods rich in nutrients (e.g., selenium, flavonoids, folates, carotenoids, and vitamin C) positively impact cancer's management. However, foods (e.g., processed meats, smoked foods, and foods high in saturated fatty acids, sugar, aflatoxins, and salts) must be avoided (Stepien et al. 2016). Epidemiological studies have shown the association of nutrients with cancer and risk factors. Therefore, adequate diet influences cancer management (Patel et al. 2018).

4.5.5 Bone Health

Human ageing is an irreversible and inexorable process characterised by morphological, functional, and biochemical changes in the human body, including the musculoskeletal system. This system gradually changes and acquires specific structural and morphological characteristics, including loss of muscle mass, strength, and bone mass (Keller and Engelhardt 2014). As a result, the composition and structure of the bone weakens, which predisposes to osteoporosis because of the ageing process. Osteoporosis is defined as the decline in bone mass and micro-architecture, with an increased risk of fragility fractures (Demontiero et al. 2012; Keller and Engelhardt 2014; Mccormick and Vasilaki 2018).

Bone is a unique organ that aids mechanical and homeostatic functions. It undertakes a recurrent self-regeneration process called remodelling (Demontiero et al. 2012). The remodelling process replaces old bones with new ones. This degenerative process occurs in distinct areas of bone known as bone metabolic units (BMUs). Bone mass and strength are maintained in the osteoblasts and osteoclasts within the BMUs to prevent bone deformity (Demontiero et al. 2012). With ageing, this balance shifts negatively, favouring osteoclasts formation rather than osteoblasts formation. As a result of the reduced bone strength and bone mass, osteoporosis and fractures can occur in the elderly population and may lose independence later in life. Untreated age-related sarcopenia and osteopenia/osteoporosis increase the risk of falls and fractures. In addition, older individuals are more susceptible to the development of mobility limitations or severe disabilities that ultimately affect their capacity for independence (Demontiero et al. 2012).

In combination with intrinsic and extrinsic factors, ageing accelerates bone mass decline that predisposes to fractures. Intrinsic factors include genetics, peak bone mass accrual in youth, alterations in cellular components, hormonal, biochemical, and vasculature status (Demontiero et al. 2012). Extrinsic factors include nutrition, physical activity, comorbid medical conditions, and drugs. In addition, the ageing process increases the rate of bone resorption by osteoclast cells (i.e., multinucleated cells that contain mitochondria and lysosomes that are responsible for bone resorption) exceeds the rate of bone formation, so bone weakens. Moreover, this all happens because of inactive lifestyles, hormonal changes, and loss of calcium and other bone minerals (Demontiero et al. 2012; Ferrucci et al. 2014).

Risk factors for low bone density, osteoporosis, and fractures have unchangeable and adaptable factors. The following factors increase the risk of developing osteoporosis: having a fracture after age 50, family history, female gender, small bone frame, advanced age, low estrogen, amenorrhea, low testosterone levels, some medications, some chronic diseases, low calcium intake, lack of vitamin D, lack of exercise, cigarette smoking, and extreme alcohol consumption. Fortunately, many modifiable lifestyle factors (e.g., diet and activity) and drug treatment can prevent or slow the loss of bone.

Osteoporosis, characterised by low bone mass and quality, puts individuals at greater risk for often debilitating and sometimes fatal fractures. People experiencing low-impact fractures secondary to osteoporosis are at a significantly higher risk for death than their non-osteoporotic counterparts, which persists for several years post-fracture (Sözen et al. 2017). Even though the aetiology of osteoporosis is multifactorial, alterations in lifestyle (e.g., nutrition and physical activity) play a crucial role in attenuating bone loss and preventing osteoporosis. Calcium and vitamin D are well known to be vital in the acquisition and maintenance of bone throughout all life stages (Sözen et al. 2017). Furthermore, according to the National Osteoporosis Foundation, getting the recommended calcium and vitamin D intake is advised to improve bone health. In addition, taking a bone-density test, meeting with a bone healthcare consultant, regular exercise, and abstaining from alcohol and smoking is advised.

Reduction in appetite is often associated with old age. Eating less makes it more challenging to get the nutrients needed to keep muscles and bones healthy. Staying active helps keep appetite up while sticking to a healthy, balanced diet. Calcium is required for healthy muscles and bones to keep bones and teeth healthy, vitamin D helps absorb calcium, and protein is important for muscle maintenance. Eating a balanced diet helps maintain healthy body weight, while being underweight is linked to a higher risk of fractures.

Vitamin D is vital for strong muscles and healthy bones, and the body makes vitamin D from sunlight's action on the skin. People who are mainly indoors should take a daily vitamin D supplement. People who are not often outdoors (i.e., those who are frail or housebound) or are in an institution usually wear clothes that cover up most of their skin when outdoors, and people with dark skin (e.g., African, African-Caribbean, and South Asian origin) might not get enough vitamin D from sunlight. Some foods contain vitamin D (e.g., oily fish—mackerel and salmon—and eggs), foods fortified with vitamin D (e.g., fat spreads), and some breakfast cereals. Food supplies, however, cannot provide the recommended daily vitamin D intake; therefore, regular vitamin D supplements may be required (Nair and Maseeh 2012).

4.5.6 Oral Health

Poor oral hygiene is increasing globally among older people with a high level of tooth loss, dental caries, and a high prevalence of periodontal disease, xerostomia, and oral precancer/cancer. Extreme tooth loss in the elderly prevents proper chewing of food and thus affects their selected food choices. For instance, people suffering from edentulous prefer foods high in saturated fats but avoid fibre-rich foods. Edentulousness also shows a risk factor for weight loss, in addition to the problem with chewing (Azzolino et al. 2019). The risk factors associated with poor oral health and poor hygiene are related. For instance, chronic respiratory disease and diabetes mellitus are common risk factors for people suffering from periodontal disease.

Tooth loss has also been linked with an increased risk of ischemic stroke and poor mental health (Azzolino et al. 2019). Therefore, for good oral health, it is advisable that foods low in sugar, rich in protein, high in fibre, rich in calcium (e.g., cheese and dairy products), vitamin C, black tea extracts, whole-meal foods, and peanuts should be consumed (Scardina and Messina 2012).

4.5.6.1 Tooth Loss

Edentulism (a condition of having no teeth) is prevalent among older people worldwide and is positively associated with socio-economic status. Epidemiological studies show that persons of low social class or income and individuals with little or no education are more likely to be edentulous than those of higher social class and high income and education levels. As measured by the presence of at least 20 natural teeth, functional dentitions are most frequent among elderly of high socio-economic status compared to individuals of low socio-economic status (AL-Rafee 2020; Peltzer et al. 2014). There has been a positive trend towards a decline in tooth loss among adults, including older people, of some industrialised countries. Social inequality in dentate status, however, persists even in countries with advanced public dental health programmes.

Severe dental caries and periodontal disease are the primary reasons for tooth extraction (Griffin et al. 2012). At the same time, tobacco use is also a risk factor in tooth loss in people with high tobacco usage. Few epidemiological studies of tooth loss at old age have been conducted in developing countries. This is because there is a lack of oral healthcare access and dental treatment materials. Thus, patients prefer to extract the affected tooth to reduce the severe pain and discomfort encountered (Griffin et al. 2012).

4.5.6.2 Denture-Related Conditions

Denture stomatitis is a typical oral mucosal lesion of clinical importance in elderly populations. The incidence rate of stomatitis is about 11–67% in complete denture wearers. In many cases, denture stomatitis is a result of yeast colonisation to the prosthesis's fitting surface. However, stomatitis could result from an allergic reaction to the denture material or other diseases (Gendreau and Loewy 2011).

The increasing rate of denture stomatitis has been associated with the extent of the denture plaques and dental hygiene. Dental stomatitis can also occur when inappropriate or damaged dentures are used; tobacco and alcohol consumption could also be a risk factor. Other significant denture-related lesions include denture hyperplasia and traumatic ulcer; their prevalence rates in elderly denture wearers ranges from 4–26% (AL-Dwairi 2008). Denture hyperplasia is persistent in persons with ill-fitting and unretentive dentures. This is more commonly found in people who wear complete dentures than those who use removable dentures (Veena et al. 2013). The high incidence rate of denture lesions, however, is primarily attributable to excessive tobacco and alcohol consumption, lack of education, and lack of dental check-ups.

4.5.6.3 Coronal Dental Caries and Root Surface Caries

Several countries have high coronal dental caries and root surface caries among the elderly population. Data from developed countries have shown that the average number of decayed and filled coronal surfaces ranges from 22–35. In contrast, dental caries data among older people in developing countries are scarce. Globally, the data obtained on dental caries has proven public health concern in the elderly population. It has been associated with behavioural and social factors. The pattern is mainly that those who do not regularly visit a dentist, do not brush their teeth frequently, consume many sugars, and smoke suffer more from coronal and root surface caries.

4.5.6.4 Periodontal Disease

Worldwide, the percentage of the subjects with Community Periodontal Index scores 4 (deep pockets) ranges from approximately 5–70% among older people. Poor oral hygiene or high dental plaque levels are associated with increased prevalence rates and periodontal disease severity. Lack of education, infrequent dental check-ups, few teeth, and regular smoking affect older adults' periodontal diseases (Nazir 2017). Studies have shown that tobacco use accounts for more than half of the periodontitis cases in adults in some industrialised countries. Unfortunately, relatively few systematic surveys on the periodontal health status of older people have been undertaken in developing countries (Nazir 2017).

4.5.6.5 Xerostomia

Dry mouth is a common issue that affects about 30% of the ageing population. Dryness of the mouth causes dental caries, eating, talking, and chewing problems in the elderly (Villa et al. 2014). Because of low salivary flow, oral dryness is associated with the aged and mostly the female gender (Villa et al. 2014). Furthermore, the high rate of xerostomia in the elderly population has been linked to drug use, which could cause low salivary stimulation (Miranda-Rius et al. 2015). The drugs most responsible for dry mouth are tricyclic antidepressants, antipsychotics, atropine, beta-blockers, and antihistamines. Dry mouth complaints are persistent in patients treated for hypertension, psychiatric, or urinary problems. Smoking is another crucial risk factor for dry mouth.

4.5.6.6 Oral Precancer and Oral Cancer

Cancer of the oral cavity is higher in the elderly population, and it is more common in the low-developed countries than in developed countries. The prevalence of leukoplakia and lichen planus in older people ranges from 1.0–4.8% and 1.1–6.6%, respectively. Leukoplakia is common among men; lichen planus is associated with the female gender. Tobacco use poses the most significant cause of oral cancer and premalignant lesions, including leukoplakia. However, heavy alcohol consumption is also a substantial factor in these conditions. Socio-economic determinants (e.g., lack of education and lower income earners) have been risks for leukoplakia, while moderate to high-income earners, who can afford high fruit and vegetable intake, are protected because of carotenoids and vitamin C in the fruits (Yardimci et al. 2014).

Diet plays a vital role in preventing oral diseases, including dental caries, dental erosion, and developmental defects. Micro-nutrient deficiencies like B-vitamins are first sighted in the mouth, including glossitis, cheilitis, and angular stomatitis. Malnutrition impairs the severity of oral infections and contributes to life-threatening diseases such as noma, dehumanising oro-facial gangrene (Scardina and Messina 2012).

Oral cancer is the eighth most common cancer globally, with a high prevalence in developing countries and increasing rates in some developed countries—for example, Denmark, Germany, Scotland, and Eastern Europe (Rodríguez-Molinero et al. 2021). Diet is a preventable risk factor for oral cancer. Nutrients (e.g., iron, selenium, and vitamins E, A, and beta-carotene) have produced equivocal results, and vitamin C has shown a protective role in some studies (Ghantous and Abu Elnaaj 2017; Rodríguez-Molinero et al. 2021).

Dental erosion is the irreparable loss of dental hard tissue (i.e., enamel and dentine) chemically removed by acids without bacteria. Dietary acids (e.g., citric, phosphoric, ascorbic, malic, tartaric, oxalic, and carbonic) are found in fruits and fruit juices, soft drinks, and vinegar. Therefore, the consumption of several acidic foods and drinks, including fruit juice, soft drinks, vinegar, citrus fruits, and berries, has shown an association with dental erosion (Chu et al. 2010). In addition, dental erosion increases with age for those with the highest intake of soft drinks.

4.5.7 Mental Health

Mental health is a significant disease of the aged population. Alzheimer, dementia, depression, and mood disorder are common mental health challenges faced by the ageing population. Studies have shown that foods (e.g., fruits, vegetables, whole grains, seafood, and low-glycaemic ones) should be consumed to manage mental health (Low Dog 2010). In addition, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in fish oil have been investigated for an antidepressant effect on the body. Thus, omega 3 fatty acid-rich foods (e.g., walnut, canola oil, flaxseeds, salmon, herrings, sardine, mackerel, and soybean oil) are beneficial to improve mental health. In addition, foods rich in B vitamins (e.g., thiamine) helps to improve cognitive development in the elderly (Bourre 2006; Rao et al. 2008).

4.6 Conclusion

Geriatrics are faced with several health conditions that could reduce their mobility and quality of life. The dietary approach in managing health-related conditions in the elderly (e.g., consumption of food containing dietary fibre, fermented dairy products, antioxidants and bioactive compounds, calcium, and vitamin D) would prevent and manage the development and progression of chronic diseases in the elderly. This has been supported and several studies have investigated and shown that the role of diets in the health management of geriatrics has a significant impact.

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Chapter 5
Genetically Modified Crops in Africa: Perspectives and Safety Concerns

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5.1 Introduction

The application of genetic engineering, a modern biotechnology technique ,offers the possibility of accelerating productivity and further enhancement of crop quality through gene transfer. Genetically modified (GM) crops are engineered using recombinant DNA techniques. Through gene transfer, traits that confer resistance to diseases, pests, herbicides, environmental hazards with improved quality characteristics (e.g., taste, nutritional value, color) are inserted into the crops (Asante 2008). The gene of GM crops are modified by inserting gene sequence known as "transgene". The genes are mostly inserted from a completely different plant or specie to achieve a desired trait. Globally, GM foods and non- GM food crops are being produced and commercialized, including *Bacillus thuringiensis (Bt)* Cowpea, corn, and cotton. Other examples are the herbicide-tolerant cotton, soybean, and virus-resistant, papaya (Food and Agriculture Organization (FAO) 2012).

In the past 20 years, GM crops that have been commercialized include tomatoes, maize, soybeans, cotton, rice, potatoes, squash, canola, and papaya. In many countries, the GM soybeans, maize, and cotton play a key role in the agricultural sector owing to their widespread cultivation (Shukla et al. 2018). Presently, several GM crops with phytoremediation, biofortification, and biopharmaceutical qualities are

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being developed, while some are in confined field trials yet to be commercially released (Shahid et al. 2016).

Transgenic crops also are developed with the aim of expressing foreign proteins having industrial and medicinal value. These proteins include cry toxins from *Bacillus thuringiensis,* which is pest-resistant and acts as an antigen used for vaccinations (Jhansi and Usha 2013). As a result of the development of biotech (i.e., genetically modified, GM) crops, which express various novel traits (e.g., pest and disease resistance, herbicide tolerance, insect resistance, enhanced nutritional quality, and so on), GM crops is now cultivated on a large scale. According to the International Service for the Acquisition of Agri-biotech Applications (ISAAA 2019), 2.7 billion hectares of biotech crops have been cultivated since 1996 with soybeans, maize, cotton, canola, and alfafa rated as the top five biotech crops in the world.

5.2 Development of GM Crops: Evolution Techniques

5.2.1 Traditional/Conventional Methods

For several years, conventional or traditional plant breeding procedures have always been deployed to alter the traits of crops to have better ones. Conventional plant breeding techniques involve using conservation methods for the alteration of plant genomes within the natural genetic boundary of the crop (Graham-Acquaah et al. 2015). For breeders, it is important to regulate the quantity of genes that are of interest. Breeders apply methods based on the cross-pollinating, self-pollinating, or clonally propagated reproductive types of the plant (Ahmar et al. 2020). The basic methods of breeding of self-pollinated crops are pedigree, mass selection, bulk population, pure line selection, single seed descent, crossing, multiline, and composites (Kaiser et al. 2020). The result of conventional breeding is a new variety with desired features that may be employed by farmers in the environment for which it was produced (Qaim 2020).

Although labor intensive and time consuming, the process involved the shuffling of genes from one plant to another (Asante 2008). Traditional breeding methods, which concentrated more on complementarity between parental characteristics, involved examining and cross-breeding parents. The outcomes are unknown at the genetic stage because they may pass the gene (or trait) of preference, but also result in the adoption of other undesirable traits. A significant amount of time and effort is required to differentiate between undesirable and favorable traits, and this is not always economical. For example, over several growing seasons, plants need to be backcrossed repeatedly to introgress the gene of interest to a homozygous state.

The conventional and traditional breeding methods, which take about 10–15 years, are inadequate to meet the food and nutrition requirements (Singh et al. 2021). In the last decade, remarkable progress has been recorded on scientific and technical advances of developing desirable crops.

5.2.2 Modern Biotechnology Methods

Modern biotechnology methods of breeding new plants have proved to be economical and important for agricultural biotechnology. These methods include tissue culture, marker-assisted selection, and genetically engineered plants/food.

5.2.2.1 Tissue Culture

Tissue culture methods are the most-used biotechnology techniques for functional gene studies, plant developmental processes, plant breeding, commercial plant micropropagation and crop enhancement, and virus removal from infected materials to yield high-quality healthy plant material, which are conserved and preserved (Loyola-Vargas and Ochoa-Alejo 2018). The tissue culture technique enables development of enhanced plant variety within a brief period, using tiny fragments of tissue called explants; this approach can grow hundreds of thousands of plants in a continuous process (Oseni et al. 2018). Plant tissue culture entails the in vitro cultivation of all plant species under aseptic conditions, which is commonly done in a culture transfer room. Tissue culture methods usually follow a due process of initiation where the tissue of interest is obtained, introduced to the culture, and sterilized. The sterilized explant is then regenerated.

Plants that have been regenerated in vitro tissue culture are transplanted into vermiculite pots. The potted plants eventually are moved to greenhouses or growth cabinets, where they will be kept under controlled lighting, temperature, and humidity conditions for additional research (Bhatia and Dahiya 2015). The process of transferring the plants to the greenhouse is referred to as acclimatization. Through tissue culture, somaclonal variations have been produced as the most efficient approach for development of crops. This approach provides additional genetic variability, suitability for breeding of higher plants, and preservation of stable cell line cryopreservation (Bhat and Rao 2020). The pollen culture that was used to develop different varieties of rice is an example of tissue culture (Ruwani et al. 2018).

Micropropagation is a method of tissue culture used for the development of high-quality, disease-free planting seedlings and for the quick production of numerous uniform plants. Plants have been shown to mature faster by micropropagation, grow more rapidly and taller, have a shorter and more uniform development time, as well as achieve higher yields than traditional seedlings (Oluwambe and Oludaunsi 2017). Micropropagation has been beneficial in effectively producing and conserving endangered species of plants. This is a major advantage over the conventional method of breeding. Micropropagation can be achieved through various techniques such as somatic embryogenesis, organogenesis (Poonam et al. 2021), and meristem tip culture.

Meristem-tip culture is one of the most extensively used procedures for removing viruses from infected plants and producing virus-free ones. This is achieved through apical meristem culture that involves clonal replication and viral elimination from diseased plants. This method maintains high genetic stability and consequently the isolated meristem-tips can be used for in vitro germplasm conservation. The short length of the meristem explant, used in this approach, has the potential to eliminate additional harmful organisms. When combined with thermotherapy and chemotherapy, meristem culture is more successful at eradicating viruses. Most plant viruses have been found to be eliminated effectively by pretreating infected plants with higher temperatures and using antiviral medications in the meristem regeneration media (Bhat and Rao 2020).

Somatic embryogenesis is a biotechnological method applied for long-term clonal replication using an in vitro plant regeneration procedure. Through this method, tissues or somatic cells develop into distinct embryos. Unlike zygotic embryos, somatic embryos can grow into whole plants without the necessary sexual fertilization. Somatic embryogenesis can begin directly from explants or indirectly through the creation of a callus—a mass of disorganized cells. Plant regeneration is performed via somatic embryogenesis by inducing embryogenic cultures from zygotic seeds, leaves, or stem segments and multiplying the embryos. This is followed by culturing the mature embryo for germination and sprout development before transferring to the soil (Oseni et al. 2018).

Organogenesis involves generating plant organs (e.g., leaves, shoots, and roots) either directly from the meristem or indirectly from undifferentiated cell masses (callus). Plant regeneration done through organogenesis involves altering the concentration of plant growth hormones in nutrient media for callus development and distinction of adventitious meristems into organs (Oseni et al. 2018).

5.2.2.2 Marker-Assisted Selection/Molecular Breeding

This modern biotechnology method allows for selection of a desired gene in plants. Marker-assisted selection (MAS), also known as molecular breeding, is a scientific process of choosing plants carrying genomic region responsible for the expression of traits of interest through molecular markers (Lema 2018).

Marker-assisted selection is a relatively recent method of improving phenotypic selection criteria by selecting genes, either indirectly or directly. It has become possible for both qualitative and quantitative trait loci (QTL) with the availability of several molecular markers and genetic maps. This approach is often used for breeding strategies such as selection of simple traits or QTLs (Lema 2018). The techniques of MAS have been broadly used to justify the discovery and cloning of hundreds of genes across many species (Ji et al. 2016). The accessibility of a molecular marker is determined by its capacity to reveal polymorphisms in nucleotide sequences that allows segregation of various molecular marker alleles (Hasan et al. 2021).

Molecular markers are nucleotide sequences that can be evaluated using polymorphisms found in the nucleotide sequences. Polymorphisms occurs based on insertions, deletions, duplication, translocation of nucleotide sequence, and gene mutation (Hasan et al. 2021). The polymorphisms are revealed using molecular techniques such as amplified fragment length polymorphism (AFLP), restriction fragment length polymorphism (RFLP), microsatellite or simple sequence length polymorphism (SSR), single nucleotide polymorphisms (SNPs), cleavable amplified polymorphic sequences (CAPS), random amplified polymorphic sequences (RAPD), single-strand conformation polymorphisms (SSCP), and others (Khlestkina 2014).

According to Hasan et al. (2021), molecular markers are classified into three groups:

1. Dominant or co-dominant markers: These are used based on the type of gene action.
2. PCR-based molecular markers or hybrid-based molecular markers: These are grouped based on detection methods of molecular markers.
3. Transmission route of molecular markers (i.e., maternal organelle inheritance, maternal nuclear inheritance paternal organelle inheritance, or biparental nuclear inheritance).

Lema (2018) and Hasan et al. (2021) reported the application of MAS in the following:

- Cultivar identity/assessment of purity
- Marker-assisted introgression
- Identification of genomic region selection
- Early generation selection
- Evolution and phylogeny
- Study of heterosis
- Marker-assisted backcrossing breeding
- Assessment of genetic diversity and parental selection
- Marker-assisted pyramiding
- Assessment of genetic diversity and parental selection

Recent advances have been made in MAS, which includes target-induced local lesions in the genome (TILLING), virus-induced gene silencing (VIGS), genomic-wide association studies (GWAS), RNA-sequencing (RNA-seq), and genome editing cluster regularly interspaced short palindromic repeat (CRISPR) (Hasan et al. 2021).

Marker-assisted selection has significantly reduced the time it takes to develop new crop varieties by assisting in the collection of targeted alleles, which are challenging, costly, and time consuming, in scoring phenotypes (Hasan et al. 2021). This method is being applied in successful introgression of desired genes into different plants; examples include improved beta-carotene in cassava, banana, and rice (ISAAA 2014).

5.2.2.3 Genetic Engineering

This is a process of genetic modification, which entails the insertion of a new gene into the plant's DNA. This technique is used to develop plants with a desired trait (Oluwambe and Oludaunsi 2017). Studies have shown that genetic engineering technology permits the repetitive development of genetically engineered crops thereby creating potential for increasing crop breeding program efficiency, safeguarding germplasm resources, and enhancing agricultural product quality and outputs (Fang et al. 2016). Through this technology, improvement on food nutritional quality, yield, shelf life, tolerance to environmental adversity, pest and disease resistance, has been achieved.

Genetic engineering process differs from the traditional/conventional breeding method because the gene technologist simply transfers genes from one organism to another by means of a "cutting-copying-pasting" laboratory technique. Individual genes responsible for desired features can be introduced into the plant using recombinant DNA methods without causing all the additional genetic alterations that traditional crossbreeding or induced mutagenesis causes (Qaim 2017). Plants derived from this method comprise combined genes from various organisms and are referred to as GM crops. Genetically modified crops are also called transgenic crops, which indicates that transgenes or foreign genes were inserted into the plant.

5.2.3 Genetic Engineering Techniques

Biotechnology tools and techniques are applied to cut-and-paste foreign DNA into another species. Genetic engineering (GE) methodology for manipulating genes and cloning recombinant DNA molecules entails various tools, as listed in Table 5.1. According to Kurnaz (2015), the DNA techniques used for GE methodology are DNA Gel Electrophoresis, Realtime PCR, Nucleic acid blotting, Polymerase chain reaction (PCR), DNA sequencing, and Next generation sequencing (NGS). GE technology also has five main phases, namely: trait discovery, proof of concept,

Table 5.1 Genetic Engineering Tools

S/N	Tools	Subtypes of tools
1.	Modifying enzymes	Polymerase Ligases Recombinases Akaline phosphate
2	Vectors	Plasmids Phage vectors Cosmids and phagemids Specialist vectors (e.g., expression vectors, bacterial artificial chromosomes, yeast artificial chromosomes)
3.	Restriction endonucleases	Type I Endonucleases Type II Endonucleases Type IIs Endonucleases Type III Endonucleases Type IV Endonucleases Restriction Mapping

Source: Kurnaz (2015)

early development, advanced development, and regulatory approval (Bullock et al. 2019).

Presently, several methods are used for transfer of genes in GE, including the gene-gun (biolistic), agrobacterium tumefaciens method (ATM), microinjection, electroporation, and ultrasound-mediated gene transfer in plants. Electroporation, microinjection, and the gene-gun methods are direct ways of transferring genes. The electroporation method uses an external electrical field for transfer of genes while microinjection process is carried out with metal microinjection needles or glass micropipettes. The ultrasound-mediated gene transfer applies a mechanical process of gene transfer into plant cells through an ultrasound-mediated membrane perforation, known as sonoporation (Zolghadrnasab et al. 2021).

The electroporation method uses external electrical field for transfer of genes while a microinjection process is carried out with metal microinjection needles or glass micropipettes. Electroporation and ultrasound are very versatile because they rely on the disruption of the cell membrane and depend less on the type of cells (Zolghadrnasab et al. 2021). The gene-gun method is based on particle bombardment of cells while the agrobacterium method uses vectors to indirectly transfer genes to plant cells.

In developing GM crops, the most frequent methods employed are the biolistic and agrobacterium methods.

(a) *Biolistic* (*Gene-gun*): This direct method involves bombarding plant cells with gold microprojectiles coated with DNA or inserting of DNA directly into protoplasts using liposomes. The biolistic alteration signifies a direct technique that permits shooting a spherical gold or tungsten bullet of 0.4–1.2 pm, enclosed with constructs of gene of interest at speeds of 300–600 m/s (Eddo et al. 2020) with a gene-gun. These constructs get to the nucleus, chloroplasts, and/or mitochondria in which DNA will be integrated (Eddo et al. 2020). The modified cell can then be used to regenerate a new organism (Asante 2008).
(b) *Agrobacterium tumefaciens method* (*ATM*): This is an indirect method, which is carried out by adding the DNA to a bacterium with the hope that it can transfer the DNA to the plant's genetic code (Bullock et al. 2019). The ATM uses bacterial enzymes that recognize, cut, and join DNA at specific locations acting as molecular "scissors-and-tape". The method works by employing some species of *Agrobacterium tumefaciens* or viruses as vectors. The most effective vector for the transfer of exogenous DNA using this method is the tumor-inducing plasmid (Ti plasmid) of the *Agrobacterium tumefaciens*, bearing a gene marker for gene selection. The bacterium is modified to contain one or more genes of interest as well as a marker gene required for the selection of cells that carry the genes (Eddo et al. 2020).

The bacterium transfers a plasmid, which contains a section of the DNA that will be incorporated in the genome of the plant. Plasmids are tiny circular DNA fragments that can replicate themselves and convey genes between bacteria as vectors. The merged bacterium and plant cells are co-cultivated to achieve the integration of a desired gene with DNA sequences that controls transcription and a reporter gene that confirms the existence of the gene of interest (Gao and Nielsen 2013). This method is beneficial for transfer of DNA pieces with distinct ends and frequently is used for the transfer of genes to monocotyledon and dicotyledon plants.

Sheweta et al. (2010) summarizes the stages of GM crop development as follows:

1. Identifying an organism that has the desired characteristic, locating precise gene producing these features, and cutting off the DNA using a suitable genetic tool.
2. Attaching the gene to a carrier to integrate the gene into the plant cells that will be modified. The carriers are generally vectors (e.g., plasmids).
3. To guarantee that the gene works properly when it is delivered into the plant, a 'promoter' is attached to the gene and carrier.
4. Insertion of a gene of interest together with carrier and promoter into bacterium and is allowed to reproduce to create many copies of the gene, which are then transferred into the plant being modified.
5. Examination of plants to ensure that they have the desired physical characteristic conferred by the new gene. This can be done using DNA techniques, such as PCR, and gene sequencing.
6. Breeding of genetically modified plants with conventional plants of the same species to subject the seeds produced by these plants for testing and commercialization in the future.

The development process of GM crops from the initial stage has a long-developing timeline characterized by various technical processes, costs, and time (Bullock et al. 2019).

In the last three decades after various research approaches for preparing genetically engineered crops, the first transgenic vegetable the "Flavr Savr tomato" was developed in 1994, approved for consumption and available for commercial use to the masses (Mathur 2018; Bullock et al. 2019). Flavr Savr tomatoes were developed to curtail the problem of softening of ripe tomato fruit. This was done by deactivating a gene to reduce the level of *polygalacturonase,* which is a softening enzyme in the tomatoes (Mathur 2018). The tomato product was the first ready-to-eat fruit that was made using recombinant DNA technology. Development of GM crops on a commercial basis began in 1996 with GM maize, soyabean, canola, and cotton (ISAAA 2020). Since the first cultivation in 1996, the total area of cultivation for the crops are as follows; 95.9 million hectares for soyabeans, 58.9 million hectres for maize, 24.9 million hectares for cotton, and 10.1 million hectares for cannola (ISAAA 2020), resulting in increased food production, food security, and improved livelihoods.

5.3 Benefits of GM Crops

Geneticaly modified crops have been reported to be beneficial for countries that have adopted the technology. Presently the ISAAA (2020) reports about 30 countries have planted GM crops. The advantageous features of genetically modified crops are summarized in Table 5.2.

Table 5.2 Advantageous Features of GM Crops

S/N	Transgenic traits	Advantages	Crops modified	References
1.	Pest and disease resistance (e.g., *virus resistance, fungus resistance, and bacterial resistance*)	Drastic reduction of use of pesticides, It helps farmers save money on pesticides by reducing crop losses and increasing yield. It also enables reduced exposure and potential poisoning of farmers.	Cereals, papaya, squash, potato	Brookes and Barfoot (2017), Bailey-Serres et al. (2019), and Qaim (2020)
2.	Tolerance to abiotic stress	Crops with higher resilience to abiotic stress (e.g., heat, drought, flooding, and soil salinity) have been developed for environments susceptible drought.	Maize, rice, wheat, beans, and several other crop species	Hickey et al. (2019)
3.	Insect resistance (IR)	Benefits biodiversity and ecosystem. Insecticide spraying is reduced. Insect-resistant crops protect themselves against certain insect pests, hence making Farmers exposed to less hazardous compounds.	Maize, cotton, soybeans, potatoes,	Qaim (2020)
4.	Herbicide tolerant (HT)	With the use of HT crops, there is reduced-tillage practices, thus erosion problems and greenhouse gas emissions are reduced.	Soybeans, canola, corn	Smyth et al. (2014) and Perry et al. (2016)
5.	Improved product quality	It enhances the nutritional composition and ameliorates malnutrition in an effective and economic way	Golden rice Cassava	Singh et al. (2021)
6.	Modified existing traits	It helps to preserve varietal diversity for crops difficult to improve through conventional crossbreeding	Banana and cassava	Qaim (2016) and Krishna et al. (2016)

5.3.1 Improved Nutrition

Development of transgenic crops may improve food quality by increasing the nutrient content, improving stable digestion by lowering the glycemic index, enhancing taste and flavor, or reducing food substances that produce allergy. The benefits of GE in terms of improved nutrition includes food products (e.g., Golden rice), the genome of which was modified through the introduction of more copies of genes that condition the synthesis of provitamin A; the carotenoids that includes β-carotene, vitamin A, and its provitamin is a group of active biological compounds responsible for normal sight and body resistance. Golden rice was enriched using a genetic process with transgenes from maize and a common soil bacterium, *Erwinia uredovora* (Kramkowska et al. 2013). The result of this gene transfer produced an increase in the activity of the enzyme *phytoene synthase*, which translated to an increased amount of synthesized β-carotene. Subsequently, the level and bioavailability of iron was also modified, therefore making golden rice a product with high nutritive value. Golden rice is now used as a choice product to reduce malnutrition.

Through genetic modification, some plant varieties have been altered to produce desirable qualities together with improved nutritive value. Alteration of amino acid profile has been recorded as in the case of cultures of sweet lupine, enriched with more methionine molecule (Kramkowska et al. 2013). The need to change the composition of dietary lipids also has caused genetic modifications. The increasing proportion of saturated fatty acids, along with the decreased intake of mono- and polyunsaturated fatty acids, has led scientists to modify the natural composition of oil plants.

Laboratory research culminated in soybean varieties with few-fold improved oleinic (oleic) acid content and stearic acid-rich rape varieties with less consequences on health. The incorporation of genes responsible for the synthesis of unsaturated fatty acids to plant cells has facilitated the alternative development of omega-3 acids (polyunsaturated fatty acids). This is recommended for its pro-health properties (e.g., for the reduction of LDL cholesterol and triglyceride levels) in serum and for reduction of cardiovascular diseases risk (Ochocki and Stańczak 2005)

In the transgenic products, new nutritional values also have been obtained because of improvements in carbohydrate composition. The genetically modified potato variety, Amflora, is an important example of such a process. Starch, made from amylose and amylopectine, constitutes the bulk of potato bulb-bulb polysaccharides. Amylopectin is industrially used in the production of starch, paper, and textile processing. Starch synthesis involves various enzymes including granule bound starch synthase (GSBB) the principal role of which is the production of amylose. Amylopectin is exclusively produced without GSBB. It was possible to make a change allowing the potato starch composition to be modified with the preceding details. A further copy of the GSBB coding gene was used in the transgenesis process for potato bulbs.

The GE material transferred and obtained by co-repression or gene-silencing resulted in the decreasing of the enzyme's synthesis, thereby encouraging the manufacture of amylose free starch. Amflora potato was allowed to be grown in European countries exclusively for industrial purposes (Bagwan et al. 2010; Zeeman et al. 2010). Application of genetic techniques to improve plant composition through food content, components, and their improved nutritional value is becoming more widespread. An example of this application is found in the orange flesh sweet potato, which was modified to reduce malnutrition. Table 5.3 describes the genetically modified crops altered to improve quality.

Table 5.3 Benefit of GM Crops

Food	Benefits from genetic modifications	Reference
Bt cowpea	Modification was done to resist pod borer (Maruca pest) which causes over 60% yield loss.	Miko et al. (2018)
Golden rice	Developed to provide improved content of β-carotene and iron bioavailability	Singh et al. (2021)
NEWEST rice	Modified to increase rice productivity in flooded, poor Nitrogen and saline environments.	GAIN (2017)
Bt cotton	Modified to reduce pesticide usage.	Mathur (2018)
Vitamin A cassava	Biofortified virus-resistant and high-yielding cassava which provides up to 100% of daily vitamin A needs	https://www.harvestplus.org/
Tomato	Developed for increased content of dry matter, prolonged ripening process, intensification of aroma and virus resistance	Kramkowska et al. (2013)
Bt eggplant	Modified to significantly reduce use of insecticide, higher yields, and incomes among smallholder vegetable growers	Ahmed et al. (2019)
Africa-biofortified sorghum	Modified for improved levels of vitamin A, iron, and zinc	Miko et al. (2018)
Potato	Higher amylopectin content Cyclodextrin production Resistance to viruses and potato beetle Lower alkaloids content	Kramkowska et al. (2013)

5.3.2 *Pest Resistance*

In genetic modification, pest-resistant trait is often incorporated into the plant. Genetic modification provides insect pest protection. This increases the yields of crops significantly because the rampant harm caused by pests is drastically reduced as well as the use of pesticides. An example is the soil bacterium *Bacillus thuringiensis* in Bt maize, which makes crystal proteins poisonous for certain insects but relatively harmless for vertebrate and non-lepidopteran insects. Bt cotton is also an example that produces an insect-control protein (Cry1Ac) derived from the naturally occurring soil bacterium, *Bacillus thuringiensis* subsp. kurstaki (B.t.k.). The production of the Cry1Ac protein in the cotton plant provides protection against key Lepidopteran insect pests including cotton bollworm and pink bollworm (Betz et al. 2000)

The main advantages of Bt cotton are minimal use of insecticides, improved management of target insect pests, improved yield, reduced production costs, improved profitability, reduced farming risk, and improved cotton production opportunities, leading to improved economics for cotton growers (Edge et al. 2001).

Smaller amounts of pesticides used on GM crops reduces pesticide exposure to farm workers, to the communities that surround farms, and ultimately to consumers, as well as decreases the impact of agricultural pesticides on nontarget insects. Another example of pest resistant GM crop, Bt cowpea (Pod borer-resistant cowpea) that was developed to be resistant to Maruca, an insect that decreases cowpea yield by over 60%. The cowpea was developed in Australia with significant collaboration with Nigerian scientists (Miko et al. 2018).

5.3.3 Herbicide Tolerance

Genetically modified crops are engineered to be resistant to one very potent herbicide. For certain crops, eliminating weeds by physical means (e.g., tilling) is not cost-effective, so farmers also spray vast volumes of multiple herbicides to kill weeds, a time-consuming and costly method that needs caution so that the herbicide does not damage the crop plant or the ecosystem.

The crops are GM to help reduce harm to the environment by reducing the number of herbicides needed. GM crops withstand the application of powerful herbicides using genes from soil bacteria. Herbicides to which GM crops are tolerant are “broad-spectrum” weed killers, which means they can be sprayed over the entire field, killing all plants apart from the GM crop. Herbicide-tolerant crops contain transgenes that provides tolerance to the herbicide’s glyphosate or glufosinate ammonium. An example is GM soybeans that are modified to be unaffected by herbicide (Sheweta et al. 2010).

5.4 Higher Productivity

Genetically modified crops produce a high yield because they are herbicide-tolerant and pest-resistant. This technology has also been used to grow crops that are suited to unique conditions (e.g., varieties resistant to drought or crops tolerant of elevated soil salinity). Crop yields are strongly reliant on the availability of nutrients, particularly nitrogen and phosphorus, which are presently predominantly provided by chemical fertilizers. Higher-nutrient usage efficiency can boost crop yields while using less fertilizers, lowering energy consumption, and the environmental impact of agriculture (Siemon et al. 2005; Qaim 2020). Genetically modified crops provide solutions to very particular climatic conditions and allow pests and fungal infections to be managed more effectively. GM crops produce increased yield while reducing the use of pesticides, improving plant adaptation to unfavorable environments.

5.5 Phytoremediation and Environmental Monitoring

In all parts of the world, soil and groundwater contamination continues to be a major concern. To clear up heavy-metal contaminats from polluted land, plants (e.g., poplar trees) have been genetically engineered. GM plants are not all cultivated as food crops. Presently, plant-based environmental remediation is being explored as favorable clean-up technology. This technique can help boost biomass output in fast-growing plants while also improving their capacity to absorb, degrade, and tolerate various contaminants in soils and aquatic settings (Ojuederie et al. 2022). Turan et al. (2022) reported plant growth-promoting *rhizbacteria* as biological control agents in the biosorption of soil contaminants, including heavy metals and organic compounds.

At molecular genetic levels, some phytoremediation species have been identified for improvement via genetic manipulation. Plants (e.g., *Arabidopsis thaliana* and *Nicotiana tabacum*) have been modified with transgenes of non-plant to improve their biochemical phytoremediation effectiveness against pollutants, such as organomercurials, trichloroethylene solvents, and nitroaromatic explosives (Sheweta et al. 2010).

5.6 Challenges and Concern of Genetically Modified Crops

5.6.1 Challenges

Over the past few years, the rapid research, development, and commercialization of GM crops has also raised serious concerns about their possible impact on the climate, biodiversity, and, ultimately, human and animal health. Biosafety issues, environmental effects, and ethical issues are some of the major challenges facing research and legalization of GM crops worldwide, including in Africa. Several news stories, reports, and documentaries on the safety of GMOs have been published regularly in the media. Ecological risk assessment of transgenic crops, the problem of gene flow, the production of secondary resistance to pests, and the ecological risks associated with pollen flow are some of the issues of gene flow, development of secondary pest resistance, and ecological risks involved with pollen flow are some of the issues, which should be addressed before release of any GM crop for open field trials and commercialization (Craig et al. 2008).

In view of the frequent development and release of many transgenic crops for open field trials and commercial cultivation, concerns have been raised about the potential risks associated with their impact on the environment, biodiversity, and human health. Over the last decade, environmental risk assessments of GMOs have been carried out widely worldwide and a robust risk-management system has been used. Many important traits have been introduced into plants, and there is an urgent need in many countries to resolve their effect on agriculture and agricultural practices (Shukla et al. 2018)

5.6.2 Concerns

Genetically modified crops have raised a lot of concern as regards to its safety, adverse health, and environmental effects. The concerns and fears expressed by the consumer is induced by the perceived effects of genetic modifications because of the molecular biology techniques deployed that interfere with the process of natural recombination. Over the years, there has been a contentious debate that GM crops causes increased antibiotic resistance, presence of toxins, fungi, or toxic metals and increased cancer risks in humans, and that it degrades the nutritional food value, produces new allergens, and other potential risks (Bøhn and Cuhra 2014; Shubert 2013). It has also been reported that DNA breakdown during digestion eliminates the possibility that intact genes capable of encoding foreign proteins will be transferred to gut flora (Plahuta and Raspor 2007). The concerns are based on the potential risk to health and environment.

5.6.2.1 Health Risks

The human health concern associated with GM crops include food allerginicty and DNA/gene transfer.

Food Allergenicity

Allergenicity may be directly caused by interaction with usual proteins or new proteins that produce a new allergen. Food allergens are linked to alimentary proteins, and their consumption can cause skin reactions, changes in the respiratory and circulatory systems, and even anaphylactic shock, all of which can have major health consequences (Ladics et al. 2011).

In GM crops, there is an expression and synthesis of new proteins when genes are transferred from one organism's cells to the nucleus of another organism's cells. The amino acid sequence that forms the structure of a protein is the primary risk factor for the development of food allergies because of transgenic food intake. A pathogenic immune reaction resulting from a response to an antigen carried by a specific crop component is referred to as "allergy" (Kramkowska et al. 2013; Ladics et al. 2011). Food allergy is a form of adverse reaction to food products that involves the immune system's abnormal response to specific proteins found in foods. Allergen-specific immunoglobulin E (IgE) antibodies induce a common kind of food allergy. Immediate hypersensitivity responses are caused by IgE (Sheweta et al. 2010).

The potential for the development of new allergens has been described as a risk that does not directly relate to the use of GM technology but depends on the particular gene that has been introduced to a specific crop (Hug 2008; Bawa and Anilakumar 2013). Because diseases (e.g., Ebola, AIDS, Lyme, and mad cow) seem to have been genetically transferred from animals to humans, it has been speculated that about 20% of GMOs with viral pathogen-engineered genes could produce new viral strains with unknown properties (Hug 2008).

The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO/WHO 2001) defined allergenicity hierarchical methods to determine the type of allergens associated with GM foods or crops. These methods include characterization of amino acid sequences, identification of amino acid sequences that define allergenic epitopes to develop more precise sequence-screening criteria, and development of an animal model(s) that can recognize food allergens in a manner like what occurs in human disease/molecular mass. That is, the molecular mass of most known allergens is between 10,000 and 40,000 Da, and it is another element in predicting possible allergenicity of changed gene products (Sheweta et al. 2010).

Introduction of a gene expressing non-allergenic protein (e.g., GM field pea, expressing alpha-amylase inhibitor-1) may not always result in a product without allergenicity (Prescott et al. 2005). *Brassica juncea*, a GM plant expressing a choline oxidase gene caused low IgE response in mice, and a cross-reactive epitope search showed a stretch similar to Hev b 6, having some antigenic properties; however, according to Singh et al. (2006), it had no allergenicity. According to Bernstein et al. (2003), if Bt gene is expressed in many crops, farm workers exposed to the Bt pesticide may develop skin sensitization and IgG antibodies to the Bt spore extraction. Concerns have been raised about the introduction of novel proteins into foods (e.g., a GM corn variety) modified to produce a, *Cry9C* protein that has pesticidal characteristics and a high allergenicity. Consumers have reported adverse reactions after eating "Starlink" maize on many occasions (Zhang et al. 2016).

DNA/Gene Transfer

The transfer of genetic material, accompanied by its expression, directly to a living cell or an organism poses a potential risk. The risk of developing resistance to antibiotics, perceived as a risk of transferring genes of resistance to antibiotics to GM crops, is subsequently a significant aspect that has been proposed. The widespread use of therapeutic agents as modifying agents presents a risk of passing genes of resistance to human and animal food microflora (Kramkowska et al. 2013). The gene may compromise the integrity of the plant's existing genomic information, resulting in the deactivation or modification of endogenous genes. Again, such a disruption might be used to activate (or deactivate) metabolic processes that include products or toxins, as well as their detoxification (Zhang et al. 2016).

By means of horizontal gene transfer (HGT) from GM crops to human gut bacteria, antibiotic resistance can be transmitted owing to the transformation of bacteria in the food chain (Bennett et al. 2005). During splicing of a foreign gene into a plant or microbe, a link to another gene is a result; this is called an antibiotic-resistant marker gene (arm), which determines whether the first gene has been successfully spliced into the host organism. These genes can recombine in the guts of animals or people consuming GM food in conjunction with disease-causing bacteria or microbes by horizontal transfer between species.

The machinations to genetically modify an organism carry the risk of transferring antibiotic-resistant genes into the benign bacteria that makes up the microflora of human and animal gastrointestinal tracts, or to pathogenic bacteria harbored by the consumer of GM food (Zhang et al. 2016). These new combinations can lead to the increasing risk of antibiotic-resistance to public health infections that cannot be treated by standard antibiotics, such as new strains of *Escherichia coli* (Sheweta et al. 2010)

In the guts of bees feeding on gene-altered rapeseed (canola) plants, reports from German researchers have identified antibiotic-resistant bacteria (Cannon 1996). A Novartis genetically engineered Bt maize variety includes an ampicillin-resistant gene. Ampicillin is an antibiotic that is used in humans and animals to treat a type of bacterial infections. Owing to concerns that the ampicillin-resistant gene could be transferred from Bt maize to bacteria, several European countries have refused to allow Novartis Bt maize to be grown, making ampicillin a far less effective antibiotic against bacterial infections (Sheweta et al. 2010).

The introduction of a new gene can sometimes lead to an increase in existing levels of anti-nutrients, some of which, with heat treatment, cannot be reduced. Increases in anti-nutrients may be shown in one of the most widely available commercial GM products—glyphosate-resistant Roundup Ready soybean. As GM foods may be consumed raw, an increase in the level of anti-nutrients is perceived as a risk. Expert panels of the World Health Organization and the Food and Agricultural Organization of the United Nations (WHO/FAO 2005) have concluded that this event cannot be completely ruled out and should be considered by risk assessors.

5.6.2.2 Environmental Risks

Since the release of the first transgenic crop for commercial cultivation during the 1980s, environmental concerns associated to GM crops have been thoroughly investigated. Transgenic crops' impact have been studied, including biodiversity, gene flow, out-crossing, invasiveness, weediness, horizontal gene transfer, influence on non-target species, development of virulent pest strains, and the impact on soil microorganisms (Tsatsakis et al. 2017). The controversial concern concentrates on the possible risks posed by the modification of genetic materials. Environmental risks related to GM crops also include concerns (e.g., plant- and non-target) with regard to organism pesticide toxicity, threat to biodiversity, and special agronomic facilities required to limit the spread of seeds and pollen.

Plant- and Non-target Organism Pesticide Toxicity

Transgenic crops that produce insecticidal transgenes to control agricultural pests may have unintended consequences (Saxena et al. 1999). Environmentalists are concerned that the pesticidal gene product of GM crops may be detrimental to non-target creatures that ingest it—for example, the insertion of Bt genes into agricultural plants for insect control. Betz et al. (2000) reported the adverse health effects of Bt endotoxins on non-target species. They have a limited set of toxicities restricted to insect families (e.g., *Lepidoptera, Coleoptera*, or *Diptera*) depending on the Bt strain. Plant species with Bt genes have been investigated to see whether there are any changes in this limited spectrum of toxicity. Fears have been expressed concerning the possible toxicity of the Bt toxin in maize pollen to the monarch butterfly after preliminary laboratory experiments revealed higher mortality in larvae (Sheweta et al. 2010). Yet, its improbable that a significant risk to those butterflies occurs in the field (Sears et al. 2001).

Threat to Biodiversity

The United Nations/Convention on Biological Diversity (UN/CBD 1992) defines biological diversity as the variability of living organisms from all sources, including terrestrial, marine, and other aquatic environments and ecological complexes, as well as species-based and ecosystem diversity. Spontaneous mutations that result in new allelic forms in the evolutionary history of a species are subject the organisms for a period of adaptation to a new gene. The modification of a single element has an impact on the entire group. In the case of GMOs, where an exogenous gene has been injected into a receptive organism, the integration and production of the exogenous gene disrupts the network of genes. This disruption alters the network's orchestration, causing the breakdown of epistatic relationships, changes in feedback mechanisms that regulate gene expression, the emergence of mutations by inactivating other genes, and other interactions that may turn genes in the host genome on or off (Grisolia 2005).

The GM soybean is an example of a transgenic plant adapted to a novel gene. Inserting the agrobacterium gene, CP4- EPSPS, disrupted gene network harmony and altered the metabolism and synthesis of lignin—a component that physically sustains the plant (Grisolia 2005). When such a GM soybean is planted in soils with temperatures above 45 °C, the stem becomes unable to endure the heat and thus degrades. Whenever the integrated function of an organism's genes is altered, the change may be more detrimental than advantageous because it involves the altering of a biological model that was the result of a protracted evolutionary process.

5.7 Safety Assessment of GM Crops

The need to ensure food security for the rapidly growing global population will necessitate an increase in food production by 70% by the year 2050 (Delaney 2015; Giraldo et al. 2019). Although modern agricultural biotechnologies, involving recombinant DNA techniques, are a possible solution to increasing productivity and improving quality, new crop varieties—GM crops—arising from such technologies are subjected to safety assessments to fulfill regulatory requirements prior to marketing. These assessments target evaluating the impact of the varieties and their products on human, animal, and environmental health. Prior to the release of GM crops into an environment, scientific assessment and biosafety measures are carried out over a long period of time to determine the safety of them compared with its conventional counterparts.

The product safety assessment of GM crops is based on the history of unmodified plants, new traits introduced, the modified plant, its intended use, and the environment into which it is to be released. Safety assessments for foods derived from GM crops are conducted based on substantial equivalence (SE). A safety standard anchored on the principle that existing non-GM food crops with a history of safe use can be used to compare with GM crops with regard to composition, toxicity, allergenicity, and nutritional data (Ladics 2019).

The safety assessments of GM crops are tiered into components that may differ among various legal jurisdictions (Alexandrova et al. 2005). Areas of convergence exist, however, with respect to required scientific evidence that must be provided in any safety assessment. They include a detailed molecular characterization of the transgene (s) and its flanking regions within the genome as well as methodologies for tracking the specific GMO, food safety data (e.g., toxicological, allergenicity, compositional analysis data), and data from environmental safety studies (Van Haver et al. 2003; König et al. 2004; Kou et al. 2015).

5.8 Molecular Characterization of GM Crops

Molecular characterization serves as the foundation for all GM safety assessments by providing descriptive and verified information on the structure and expression of the insert(s), as well as the stability of the intended trait(s) (Kou et al. 2015; Giraldo et al. 2019). It also provides a baseline on which to base detection and identification tools to be developed to comply with regulatory requirements of labelling and traceability.

Molecular features pertaining to the GM crop's genome (e.g., insertion site(s), transgene sequence, quantity of inserted transgene(s), flanking regions, transcripts, expressed proteins, and metabolites) are critical in determining or identifying both intended and unintended effects of the transgene (Kou et al. 2015; Li et al. 2017). With the molecular characterization data, regulatory bodies ascertain whether insert(s) did or did not disrupt any functional genes, create new open-frames, or allow for the insertion of any back-bone DNA (Delaney 2015).

5.8.1 Methods Used for Molecular Characterization

In characterizing GM crops at the molecular level, approaches useful in genomics, transcriptomics, proteomics, and metabolomics are employed. Of these, PCR-based approaches are the methods of choice (Arulandhu et al. 2016; Li et al. 2017). For example, in determining flanking regions of transgenes within the genome, PCR-based genome walking approaches, such as thermal asymmetric interlaced PCR (TAIL-PCR), inverse PCR, and ligation-mediated PCR (LM-PCR), have been deemed appropriate (Liu and Chen 2007; Jia et al. 2017). For ascertaining copy numbers of inserted transgenes, quantitative PCR and digital PCR have been shown to be more accurate, robust, and cost-effective when compared to the protein-based Southern-blotting technique (Yang et al. 2005; Li et al. 2017).

These PCR-based approaches, however, require prior knowledge of exogenous sequences, thus are not very useful in ascertaining GM crops' molecular characteristics that are undocumented. Given the diversities of GM crops currently approved for commercialization and the increasing complexities associated with crops derived from new, emerging technologies (e.g., gene editing), it is becoming more appropriate to develop more efficient, accurate, and cost-effective methods (Li et al. 2017).

5.8.2 Methods Used for Tracking GM Crops

The testing of crops for genetic modification is critical to ascertaining their legitimacy and allows traceability in any given jurisdiction.

5.8.2.1 Food Safety Assessment

Whole foods and edible fractions from crops obtained via modern biotechnology must be assessed for safety using strategies to ascertain their substantial equivalence to their non-GM counterparts with a history of safe use. Although it is not expected that both categories will be equivalent, it must be demonstrated that transformation did not result in unintended effects to extents that would render such foods unsafe for humans and animals. A statement from the Organization for Economic Co-operation and Development (OECD) noted briefly that a new food or food component, confirmed to be basically equivalent to an existing food, can be treated in the same way in terms of safety because no additional issues are anticipated (OECD 1993; Delaney 2015). In evaluating food safety of foods from GM crops, two objectives are pursued: the safety level of the expressed protein and the presence/absence of unintentional effects with regard to composition arising from the transformation or expressed protein to the whole crop.

Although science-based organizations and regulatory bodies were formerly flexible with regard to food safety data requirements for individual crops, there is currently a data-driven paradigm that has been developed and adopted by several countries to determine the safety of foods derived from GM crops (Delaney 2015). Such datasets are required from tests on allergenicity, toxicity, compositional analysis, as well as feeding studies.

5.8.2.2 Allergenicity

Food allergens are proteins with the capacity to elicit specific hypersensitive immune reactions in humans and animals. Although allergenic proteins are few when compared to numerous proteins contained in most crop plants, the deliberate manipulation of a plant's genome to modify the genetic make-up might alter their allergenic potential to extents that significantly increases levels of endogenous allergens or the introduction of a known or novel allergen to the food supply (Dunn et al. 2017). Nordlee et al. (1996) reported the unintentional transfer of the allergenic protein, 2S albumin, from Brazil nut (*Bertholetiae excelsa*) to soybean (*Glycine max*) with the original intent of increasing the soybeans methionine content. The GM soybean has never been commercialized.

Allergenicity assessments evaluate the expressed protein as well as the host crop with the aim of demonstrating the safety of the GM crop in comparison to its non-GM counterpart with a history of safe use (EFSA 2010; Ladics 2019). In other words, such assessments are designed to ensure dissimilarity of novel proteins with proteins capable of cross-reacting with antibodies present in people with allergies. The weight-of-evidence approach for allergenicity assessment encompasses a protein sequence homology to known human allergens; source history of gene(s) exposure and safety; resistance to digestion by proteases of the gastrointestinal tract; resistance to heat treatment; glycosylation status, and when necessary, specific IgE binding tests with sera from corresponding allergic subjects (EFSA 2010; Delaney 2015; Dunn et al. 2017; Ladics 2019).

Bioinformatic tools and databases are invaluable in comparing the sequences of novel proteins to known allergens to determine levels of similarity. A very useful database for common human allergens is www.allergenonline.org. Guidelines from regulatory bodies proffer that proteins in GM crops with sequence similarity of a minimum 35%, over an 80 amino acid sequence, stretch with known allergen(s) and are considered risky for cross-reactivity (Codex 2003; Delaney 2015).

Evaluating the history of safe use of a gene source involves assessing whether the source of the gene(s) naturally causes an allergy. Therefore, crops (e.g., peanuts) are unlikely sources for candidate genes for use in GM crops because peanuts are known to contain allergens (Delaney 2015). In contrast, however, genes from barley (*Hordeum vulgare*) may be considered appropriate for GM crops because barley as a crop has not been known to produce proteins that are allergenic to humans.

Allergenic proteins are usually stable to degradation by digestive enzymes and acids (Delaney 2015; Ladics 2019). Thus, assessing the sensitivity of expressed proteins to digestive enzymes (e.g., pepsin, trypsin pancreatin) using *standardized* in vitro methods are effective in determining the allergenic potential of the protein. Not all non-allergenic proteins are sensitive to digestion by digestive enzymes (Dunn et al. 2017; Ladics 2019); therefore, tests should be employed in combination with other approaches to assess the safety of the expressed proteins.

Although some regulatory bodies advocate for tests (e.g., stability of expressed proteins to heat), some authors argue that thermal stability does not always correlate with allergenic risks (Privalle et al. 2011; Ladics 2019); thus, they have no predictive value in assessing the allergenicity potential of GM crops. Even though several allergenic proteins are glycosylated, many glycosylated proteins are not allergenic; consequently, the glycosylation status of an expressed protein should be considered in context of the overall weight-of-evidence approach for the protein's allergenicity potential.

5.8.2.3 Toxicity

There are naturally occurring components of food crops with proven adverse effects when consumed. Notable examples are cyanides in cassava and ricin in kidney beans. Ascertaining the toxigenic potential of foods derived from GM crops involves biochemical characterization of the expressed protein, determination of amino acid sequence homology to known toxins, and oral toxicity studies based on an animal model. Studies to determine the toxicity potential of GM crops are conducted on a case-by-case method that aims to detect active compounds with the potential of producing unexpected toxic effects in humans and animals (Van Haver et al. 2003; Giraldo et al. 2019).

Though some methods used in assessing toxicity potentials are like those for allergenicity in terms of history of safe use, bioinformatics, and response to digestive enzymes, salient differences exist. A notable example is the unavailability of annotated databases for toxic proteins to which novel proteins can be compared. Furthermore, there are no baselines that aid in determining similarity between any two (2) proteins, as observed with allergenicity in which 35% identity, over an 80 amino acid sequence suggests significant similarity in structure and therefore function (Delaney 2015).

Other methods employ acute (14 days), sub-acute (28 days), or chronic (90 days) toxicological studies in laboratory rodents using purified toxic proteins with presumed mechanisms of action (Giraldo et al. 2019). Often, these studies are designed using OECD guidelines with regard to daily oral dose limits, number of rodents, variables to be monitored (e.g., histopathology, clinical chemistry, organ weight, and so on), and housing (OECD 1993). Although one approach applies oral toxic protein doses of 2000 mg/kg of body weight, as limits recommended by OECD, another doses at amounts 1000 times higher than can be obtained from the edible parts of the GM crop. The sole aim is to ascertain the safety of expressed proteins produced in the crops (Delaney 2015). In recent times, however, high-throughput profiling omics techniques, including transcriptomics, proteomics, and metabolomics, show potentials as promising approaches in detecting unintended toxicity potentials in GM crops (Ricroch et al. 2011).

5.8.3 Compositional Analysis

The compositional analysis of a GM crop in comparison to its non-GM counterpart is critical to determining food safety, and it is part of the weight-of-evidence approach for ascertaining the presence or absence of unintentional consequences arising from genetic modification. Though compositional variation in key nutrients, anti-nutrients, metabolites, and toxins naturally exist between varieties owing to genetics, environmental as well as agronomic factors, determining significant compositional changes in GM crops may suggest unintended changes have occurred. When compositional analysis shows significant differences between GM crops and their non-GM counterparts, it may be necessary to conduct animal feeding trials, as recommended in several guidelines (WHO 1991; OECD 1993; ILSI 1996), to confirm whether such differences are biologically relevant. Information on the range of concentration for individual components of non-GM crops can be obtained from https://www.crconcentration.org/query/index.html.

5.8.4 Environmental Studies

Environmental safety data are required as a part of a safety assessment when a GM crop is to be deregulated in a defined geographical jurisdiction. These assessments are conducted to ascertain whether a novel GM crop directly or indirectly affects factors of the natural environment (e.g., biodiversity, soil and water quality, weed control) or whether its transgenes can be transferred to wild relatives (Devos et al. 2016; Giraldo et al. 2019). The transfer of genes between sexually compatible varieties of plants is called gene flow, and its occurrence is minimized by the concept of coexistence.

5.9 Current Status of GM Crops in Africa

In Africa, food production per capita is falling and hunger and malnutrition afflict at least one in three people (James 2008). The conventional practices in Africa are not sufficient to feed the population, which increases daily. To achieve food security, the use of GM crops has been proposed. Genetically modified crops, comprising both food and non-food with novel traits, have been developed and released for commercial crop cultivation. Soybean, maize, canola, and cotton are the most important crops grown commercially across the globe for pest resistance and herbicide tolerance. Despite the challenges and contentious debate on safety of GM crops, more of such crops are still being developed, some of which are in confined field trial and others have been commercialized. In Africa, there has been resistance to this technology because of ideological beliefs, political reasons, and lack of scientific knowledge (Shukla et al. 2018)

Public perception, consumers' beliefs, myths, and lack of knowledge have influenced the use of GM crops; the level of acceptance of them is low. The adoption of GM crops at governmental and industrial levels in most African countries is still below probability. An evaluation of acceptability, regulations, and actions in the countries revealed the complicated and numerous challenges that impede the adoption of GM foods, negatively affecting them (Wesseler et al. 2017). Although the progress is slow, there seems to be a new receptiveness for GM food among some African countries. The continent is undergoing a new wave of acceptance.

According to recent research from the International Service for the Acquisition of Agri-biotech Applications (ISAAA 2020), huge challenges to poverty and hunger exist. Africa has been selected as the region having the greatest potential to gain from biotech crop adoption. In 2019, the continent increased the number of countries that have adopted biotech crops, placing it ahead of the rest of the world. Presently, progress has been made in adopting GM crops because seven countries have commercialized the use of them: South Africa, Sudan, Eswatini, Malawi, Ethiopia, Nigeria, and Kenya (ISAAA 2020). According to ISAAA Brief 55, Mozambique, Niger, Ghana, Rwanda, and Zambia have achieved significant advances in biotech agriculture research, legislation, and acceptance. Uganda has made considerable progress toward the completion of multi-location field experiments for commercial approval of GM crops, whereas Tanzania expressed some interest in such crops (Gebretsadik and Kiflu 2018).

Globally, 29 countries have adopted the use of GM crops, and they have put in place biosafety regulatory bodies to oversee the adoption of the technology. In some of the African countries (e.g., South Africa, Egypt), there are measurable results in the cultivation of GM crops. Ethiopia and Nigeria are becoming aware of the technology and concerned professionals and rights groups are participating (Gebretsadik and Kiflu 2018). Public perceptions about GM foods, however, continue to change from country to country and across the globe (Cui and Shoemaker 2018). Genetically modified crop production and cultivation require getting a certified seed.

Growers must buy GM seeds every year, which makes them dependent on producers of the seeds and suppliers that charge extra for them. In addition, seed distribution for nations with poor infrastructures can be challenging. Most countries have made strategic plans and implemented procedures to address consumer and producer safety fears (Beckmann et al. 2006). It has been reported that slow regulatory capacity in African countries with various policies is a major obstacle that slows the approval process of GM crops in several of them. Ethiopia recently has invested in creating legal and regulatory mechanisms, as well as technical capability, to enable and oversee the deployment of GM cotton (Gebretsadik and Kiflu 2018). Nigeria also has established a biosafety regulatory agency to address issues related to GM crops.

According to research, even in the context of given positive facts, the public tends to emphasize its negative perception of GM foods (Vermeer and Ho 2004; Zheng 2015), as well as being more vulnerable to negative media reports because of their lack of conviction for GM technology principles and benefits. In recent years, the argument against GM foods has grown increasingly one-sided, with activists propagating falsehoods on social media about the hazards of them to human health; this is in addition to the unsupported harmful environmental impact of GM crops on transitional agricultural ecosystems. Further negative information on social media has had a substantial influence, lowering people's willingness to embrace GM foods. As a result, food-related non-governmental organizations (NGOs) have focused their efforts on fostering disputes (Cui and Shoemaker 2018); this has hampered the technology's acceptance in many African countries.

In Africa, arguments have increased the perceived risk of GM foods, although its risk is primarily based on perception rather than practice. Despite these debates, the Open Forum on Agricultural Biotechnology (OFAB) has been using the media to allay the fears of consumers by promoting the benefits of GM crops. In Nigeria, for example, OFAB, in collaboration with the Agricultural Biotechnology Department of National Biotechnology Development Agency, constantly holds a sensitization workshop for farmers on the benefits of adopting GM crops. This has resulted in positive feedback from those who participated in the field trial for GM crops.

Although, several concerns have been posed about the use, safety, and quality of GM crops, if introduced into a country by the public, crop biotechnology has been declared as safe as conventional crops by International Science and other regulatory agencies. Nearly 1783 research studies conducted between 2003 and 2013 on GM foods have not detected any significant hazard directly connected to the use of these crops (Nicolia et al. 2014). The current state of GM crops in some African countries are summarized in the following sections.

5.9.1 Status of GM Crops in South Africa

South Africa was the first African country to enact a regulatory framework to allow GM crop cultivation, import and export and also is the largest GM crop producer in Africa with the ninth largest biotech crop area globally (ISAAA 2018; Turnbull et al. 2021). The country, through the Genetically Modified Organisms Act of 1997, has approved the cultivation of insect-resistant cotton, herbicide-tolerant cotton, double-stacked herbicide-tolerant/insect-resistant cotton, with the latter accounting for about 95% of the cotton planted in South Africa (www.saasta.ac.za).

Other GM crops approved for cultivation are maize modified for insect resistance and herbicide tolerance, as well as single and stacked event herbicide-tolerant cotton.

5.9.2 Status of GM Crops in Nigeria

Nigeria has long recognized the potentials of modern biotechnologies to contribute to food security, to alleviate the impact of climate change, and to stimulate economic development for its teeming population. In March 2019, Nigeria, through the National Biosafety Management Agency (NBMA) Act of 2015 (as amended), became the first African country to approve the commercialization of a GM indigenous crop—the Pod-Borer Resistant (PBR) cowpea—two (2) years after the country approved the commercialization of insect-resistant cotton (ISAAA 2020). In 2021, the NBMA approved the commercial release of TELA maize, a corn variety modified for insect resistance and drought tolerance. Currently, permits have been issued for Confined Field Trials (CFTs) of cassava (improved shelf life), rice (enhanced nitrogen use efficiency), and herbicide-tolerant soybean (Komen et al. 2020). Permits also have been issued for importing GM maize and soybean/soybean oil for food, feed, and processing.

5.9.3 Status of GM Crops in Malawi

Malawi's biosafety regulatory instruments—that is, the Biosafety Act (2002), the Biosafety Regulations (2007), and the Biotechnology and Biosafety Policy (2008)—have allowed establishment of a fully functional Biosafety Registrar's office and a Biosafety Regulatory Committee that deliberates on applications for trials (Chaweza 2017). Currently, biosafety approvals have been issued for the commercialization of insect-resistant cotton, for CFTs of insect-resistant cowpea, and virus-resistant banana (Turnbull et al. 2021).

5.9.4 Status of GM Crops in Kenya

The government recently approved Bt cotton for commercialization in Kenya, making it the seventh country in Africa to adopt GM crops for use (ISAAA 2020). It has made great progress in establishing an efficient and effective biosafety system for the regulation of GMOs and their derived products (Muchiri et al. 2020). By enforcing the 2009 Biosafety Act No. 2, the country has approved applications for import, export, and transit of food products (e.g., maize/soybean blend), contained use, as well as confined field trials. With regard to CFTs, the crops under research include cotton, maize, sorghum, bananas, sweet potato, yam, cowpea, beans, and *gyphsophila* (Muchiri et al. 2020). In 2021, Kenya approved the general release of cassava genetically modified to resist cassava brown streak disease (CBSD). The Kenya Agricultural & Livestock Research Organization (KALRO) (Maina 2021) developed the CBSD variety.

5.10 Conclusion

Genetically modified (GM) technology is a highly controversial issue. Crops developed using the technology have the potential to reduce hunger and solve malnutrition issues. The GM crops also have the potential to protect and maintain the environment by improving productivity and decreasing use of chemical pesticides and herbicides, consequently, enhancing economic benefits for large and small farms and lowering pollution. Therefore, it should be considered an immediate solution to alleviate global hunger and malnutrition in Africa.

The GM technology will create a viable change in thinking for agriculturalists in Africa and therefore should be regarded as a significant strategy for tackling global concerns like chronic poverty, climate change, and the task of feeding 9.7 billion people by 2050. Countries should make unrelenting efforts to improve the public's opinion about GM crops by addressing risk perception issues and emphasizing the benefits of such crops. People's attitudes towards GM food safety can be misleading in the absence of an adequate understanding of the technology.

5.11 Recommendations

Generally, consumers' attitude towards the acceptance of GM crops are complexly interwoven with available information, lifestyle, and public perception. Communications directed to the public should be strengthened regarding the food security potentials of GM crops.

The government should play a particularly important role by supporting educational programs addressing consumers' fears and perceptions about GM crops. It is critical to implement the necessary safety procedures and reports to assure the public that GM crops have been fully evaluated and are considered safe. Regulatory bodies in African countries must demonstrate their ability to ensure the safety of GM crops in a harmonious and transparent manner. Biosafety issues should be tackled on a case-to-case basis at all stages of the development and release of GM crops. Robust biosafety guidelines for the evaluation of GM crops are significant and must be addressed at all levels of transgenic crop development and release. Likewise, gene flow from GM crops, factors influencing gene flow, the impact of gene flow and the transition of characteristics from GE crops to wild feeble relatives needs to be thoroughly investigated before any crop is released for commercialization.

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Chapter 6
Indigenous Leafy Vegetables and Health Management in South-Western Nigeria: A Review Based on Osun State

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6.1 Introduction

Reports on the effects of diet on human health abound in literature, providing evidence that diet can reduce the incidence of cardiovascular diseases and other conditions that cause tumor growth. A significant improvement in health status of people suffering from cardiovascular diseases, obesity, type II diabetes mellitus, cancer, and neurodegenerative diseases has been observed when they adhered to a combination of a diet rich in vegetables, fruits, legumes, nuts, beans, cereals, grains, fish, and unsaturated fats (e.g., olive oil), known as the "Mediterranean diet" (Lăcătușu et al. 2019; Martínez-González et al. 2019). The reports noted a significant reduction in cardiovascular diseases as a result of the diets rich in vegetables and other plant-based foods.

Vegetables have been reported to be essential for maintaining health because they contain dietary fiber, minerals, phytochemical compounds, and vitamins (Ülger et al. 2018; Adewoyin et al. 2019). A lot has been written about leafy vegetables including the African indigenous species, which are usually referred to as Indigenous Leafy Vegetables (ILVs), Traditional Leafy Vegetables (TLVs), or African Leafy Vegetables (ALVs). They are species used as vegetables native to or occurring naturally in a particular geographical location and are used as part of the population's traditional diet.

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Keatinge et al. (2015) defined them as “species that are locally important for the sustainability of economies, human nutrition and health, and social systems but which have yet to attain global recognition to the same extent as major vegetable commodities such as tomato or cabbage”. Most of the ILVs, apart from being used as vegetables, possess health benefits that are often used in traditional management of various health conditions. Simon (2017) reported that agricultural production of African indigenous vegetables is naturally linked to improved community nutrition and health. Still, because of urban drift, there is a corresponding change in diets, which is often accompanied by a reduction in the consumption of fruits and vegetables (especially the traditional ones) and a corresponding impact on health.

Downer et al. (2020) reported that, owing to the global epidemic of diet-related chronic diseases, food has become a formal part of patient care and treatment. They cited an “emerging but compelling body of research that indicates that the introduction of food and nutrition in the healthcare system might be related to improved health outcomes and reduced healthcare usage and costs”. Therefore, indicating “the potential for food and nutrition interventions to play a prominent role in the prevention, management, treatment, and in some cases reversal of diseases”.

In this review, we carried out an extensive literature survey to classify and detail the medicinal uses of some indigenous leafy vegetables in South-Western Nigeria and a field survey to substantiate the result of the literature survey. This chapter contains information on the ethnomedicinal uses of encountered ILVs in management of diverse health conditions in Osun State, South-Western Nigeria, and a literature study of reported medicinal uses/potential medicinal uses of the vegetables.

6.2 Methodology

The survey was carried out in Osun State, Nigeria, with its capital in Osogbo, covering an area of approximately 14,875 square kilometers. Ogun, Kwara, Ondo and Ekiti and Oyo States bound it in the South, North, East, and West, respectively. It lies between the longitude 6°51′N and 8°′N on the North-South pole, and latitude 4°05′E and 5°02′E on the East-West pole. According to Nigeria Data Portal (2016), Osun State has 4,705,589 people with thirty (30) Local Government Areas and one area office. The state is divided into three agricultural zones: namely, Ikire and Iwo (Iwo zone), Ikirun and Osogbo (Osogbo zone), Ife and Ilesa (Ife-Ijesha zone).

The state is composed of the Ife, Ijesa, Igbomina, and Osun people, all belong to the Yoruba ethnic group. Besides the Yorubas, non-indigenes from other parts of the country and outside reside harmoniously in the state. Official and business transactions are carried out using Yoruba and English languages. The traditional occupation of the people is agriculture, and they produce sufficient food and cash crops for domestic consumption and as inputs for agro-allied industries and export.

The major cash crops grown are yam, maize, cassava, millet, plantain, cocoa, kolanut, and rice. Apart from farming, indigenes also engage in trading though some are artisans involved in weaving, wood-carving, mat-making, soap making, dying, among many others. The vegetation of the state runs through secondary forest and derived savannah with natural lowland tropical rain forest vegetation. The annual rainfall is in the range of 1190 mm - 1590 mm (NIMET, 2022).

A multistage sampling procedure was adopted for the fieldwork. At the first stage, Osun State was purposively selected for the study because most of the indigenes have a very sound traditional knowledge of the usefulness of ILVs. At the second stage, two zonal areas—namely, Ife and Osogbo (representing about 35% of the total zones)—were selected using a simple random sampling technique. In the third stage, a simple random sampling technique was used to select three (3) communities from Ife zone—namely, Ojumo Ola, Yekemi, Akinlalu—and two (2) communities in Osogbo zone—namely, Ilobu and Osogbo. Lastly, a Snowball sampling technique was used to select key informants including farmers, shepherds, and housewives in all the communities selected.

The information is a combination of literature review and fieldwork. The literature review was based on available published resources in journal articles and books, as well as databases (e.g., Google, Google Scholar, Pubmed, and Research Gate). The fieldwork was basically ethnobotanical data collected through well-versed semi-structured interviews, questionnaires, and focus group discussions with key informants in the five Osun State communities (i.e., Ojumo Ola, Yekemi, Akinlalu, Ilobu, and Osogbo), all having sound traditional knowledge of useful ILVs; their answers were noted verbatim. Questions about indigenous leafy vegetables were mainly focused on local name of plant, part/parts of the plants used, mode of preparation and consumption, and medicinal uses (e.g., method of preparation, mode of application, diseases cured). The vernacular names are given in Yoruba orthography.

6.2.1 Quantitative Analysis

Relative frequency of citation (RFC): This was obtained by dividing the number of informants who mentioned the use for a species (frequency of citation, FC) by the total number of informants in the survey (N) (Tardio and Pardo-de-Santayana 2008). It has a maximum value of 1 (i.e., all participants mentioned a use for the plant species) but cannot be 0:

$$\text{RFC} = \frac{\text{Frequency of citation}}{\text{Total number of informants}\left(60\right)}$$

Cultural importance index (CII): This is a measure of the importance of a particular plant species to the community. It was calculated by dividing the number of separate uses recorded for a plant by the total number of informants (Reyes-Garcia et al. 2006). The value of this index can rise above 1 because a participant may have more than one use of a single plant species leading to several uses recorded that might be more than the total number of informants:

$$\text{CII} = \frac{\text{Number of use record}}{\text{Total number of informants}\,(60)}$$

6.3 Result and Discussion

Twelve (12) vegetable species belonging to eight families and all dicot angiosperms were encountered in the five communities being used as medicine in addition to being eaten as vegetables. The families include Asteraceae (4), Amaranthaceae (2), Verbenaceae (1), Solanaceae (1), Cucurbitaceae (1), Malvaceae (1), Araceae (1), and Portulacaceae (1). Asteraceae has the highest number of species.

6.3.1 Ethnobotanical Field Studies

Ethnobotanical studies were carried out with the purpose of documenting the medicinal uses of ILVs and comparing published literature. Sixty (60) respondents in total were interviewed comprised of 39 males and 21 females; other demographic information of the respondents is recorded in Table 6.1. They were interviewed

Table 6.1 Demographic data of respondents in the five Osun State communities

Characteristics	Frequency	Percentage (%)
Sex		
Male	39	65.0
Female	21	35.0
Age (years)		
31–40	14	23.3
41–50	29	48.3
51–60	11	18.3
Greater than 60	6	10.0
Education level		
None	14	23.3
Adult education	5	8.3
Primary education	27	45.0
Secondary education	10	16.7
Tertiary education	4	6.7
Occupation		
Farmers	6	10.0
Herbalists	18	30.0
Herb-sellers	15	25.0
Driver	3	5.0
Trader	11	18.3
Other unskilled worker	7	11.7

based on their knowledge of medicinal uses of ILVs. Table 6.2 contains the family and scientific names of all recorded plants including their vernacular (Yoruba) names as well as their main medicinal use(s) in the communities. Medicinal uses of the recorded vegetables (e.g., for indigestion, anemic diseases, and general wellness) have not been recorded. These uses were not specific because most of the informants agreed that virtually all leafy vegetables can be used for these purposes.

Quantitative analysis—namely, relative frequency of citation (RFC) and cultural importance index (CII)—were calculated. It is worth noting that while the RFC and CII points to the relative importance of plants in a community, the values here are with regard to the identified vegetables used in treating specific health challenges. There are several widely eaten vegetables of note in the study area that are not used for specific medicinal purposes.

The plants with high RFC and CII in this study are *Talinum triangulare*, *Solanum nigrum*, *Launea taraxacifolia*, and *Corchorus olitorus. Vernonia amygdalina* holds a special place among medicinal vegetables in Osun State as it has the highest FC and CII. This is not surprising because it has been reported to be a widely used medicinal plant around the world (Habtamu and Melaku 2018). Ejiofor et al. (2020) reported its use in traditional and folkloric medicine for the treatment of eleven (11) diseases and the fact that it is scientifically shown to possess activities against sixteen (16) disease conditions. They also reported the isolation of ten (10) phytochemicals from the plant.

The synthesis of phytochemicals in plant cells is affected by environmental factors; therefore, their concentrations can vary depending on the season or climate and even growth phases because the requirements of the plants at these phases differ. For example, Olukoya et al. (2018a) reported that imposing water stress at the pre-flowering stage of *C. volubile* growth enhances the alkaloids, phenol, and tannin concentrations while water stress imposed at the post-flowering stage enhances the flavonoid concentration. A study of the quantitative phytochemical constituent of *C. volubile* has shown a significantly lower alkaloid, phenol, and saponin content in the pre-flowering stage than in the post-flowering stage, showing that it is better to consume *C. volubile* in its post- flowering stage for optimal health benefits (Olukoya et al. 2018b).

This is corroborated by the report of Adegbaju et al. (2020) that the concentrations of polyphenolic compounds are highest at the early flowering stage of *Celosia argentea* and therefore could serve as a good source of phytonutrients, which could play a major role in promoting health and nutrition. Olowolaju et al. (2017) also reported that more phytochemicals were present at the flowering stage of *C. olitorius* than at the vegetative and fruiting stages.

Any part of the plant (e.g., leaves, leafy stems, woody stems, seeds, and roots) can be used as medicine depending on many factors. According to Adebo et al. (2018), various plant organs are used as medicine by diverse ethnic groups but the aerial organs of the plant are the most used as a drug owing to ease of access. In their survey, decoction (92.59%) and maceration were the only ways of preparing the drugs. In the current study, the leaves of all the vegetables were the ones utilized as medicine, either alone or in combination with other plants or materials.

Table 6.2 ILVs and their medicinal uses

S/N	Family name, Species name, Vernacular name(s), Source, FC, RFC, Number of use-records (N_{UR}), CII	Part(s) used	Main medicinal uses
1.	Amaranthaceae; *Celosia argentea* L.; Soko; CW; [FC = 7, RFC = 0.12, N_{UR} = 7, CII = 0.12]	Leaves	The vegetable is recommended along with other medicines to be consumed for hemorrhoids
2.	Amaranthaceae; *Celosia trigyna* L.; Ajefawo; CW; [FC = 19, RFC = 0.32, N_{UR} = 19, CII = 0.32]	Leaves	Leaf juice is mixed with body cream to treat eczema
3.	Araceae; *Colocasia esculenta* (L.) Schott; Omunu koko; CW; [FC = 4, RFC = 0.07, N_{UR} = 4, CII = 0.07]	Leaves	1. Young emerging leaves are ground with seeds of *Aframomum melegueta* K. Schum. and mixed with local soap; it is used to wash the head for dandruff 2. A decoction of the mature leaves is used to bath babies born prematurely to strengthen them
4.	Asteraceae; *Crassocephalum crepidioides* (Benth.) S. Moore; Ebolo; CW; [FC = 22, RFC = 0.37, N_{UR} = 22, CII = 0.37]	Leaves	They are cooked with seeds of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don., and some other non-plant materials and eaten to treat snake bites
5.	Asteraceae; *Launea taraxacifolia* (Willd.) Amin ex C. Jeffrey; Efo Yanrin; CW; [FC = 23, RFC = 0.38, N_{UR} = 33, CII = 0.55]	Leaves	1. Consumption of this vegetable is prescribed along wth other medicines for people suffering from diabetes 2. Vegetable is eaten in cases of constipation.
6.	Asteraceae; *Solanecio biafrae* (Oliv. & Hiern) C. Jeffrey; Woorowo; CW; [FC = 9, RFC = 0.15, N_{UR} = 9, CII = 0.12]	Leaves	Leaf paste is mixed with palm oil to cure cough
7.	Asteraceae; *Vernonia amygdalina* Delile; Ewuro; CW; [FC = 35, RFC = 0.58, N_{UR} = 55, CII = 0.92]	Leaves	1. Leaf is macerated in water to treat diabetes 2. Leaf juice is mixed with palm oil and drunk to treat measles 3. Leaf is squeezed and stuffed in the nostrils to control epistaxis 4. Maceration of the leaves is used for pile and hemorrhoid
8.	Cucurbitaceae; *Cucurbita pepo* L.; Elegede; CW; [FC = 3, RFC = 0.05, N_{UR} = 3, CII = 0.05]	Leaves	Leaf juice is applied to rashes and other skin diseases
9.	Malvaceae; *Corchorus olitorus* L.; Ewedu, Ewe Ooyo; C; [FC = 21, RFC = 0.35, N_{UR} = 35, CII = 0.58]	Leaves	1. They are cooked without salt and eaten to treat measles 2. They are macerated in cold water and drunk during difficult labor
10.	Portulacaceae; *Talinum triangulare* (Jacq.) Willd.; Gbure; CW; [FC = 31, RFC = 0.52, N_{UR} = 42, CII = 0.70]	Leaves	1. Leaf juice is applied to a boil 2. It is used as a cheap remedy for infant anemia

(continued)

Table 6.2 (continued)

S/N	Family name, Species name, Vernacular name(s), Source, FC, RFC, Number of use-records (N_{UR}), CII	Part(s) used	Main medicinal uses
11.	Solanaceae; *Solanum nigrum* L.; Efo Odu; CW; [FC = 23, RFC = 0.38, N_{UR} = 38, CII = 0.63]	Leaves	1. Raw leaves are eaten to suppress the effect of snake venoms 2. They are cooked as soup to treat severe stomachache
12.	Verbenaceae; *Clerodendrum volubile* P. Beauv; Efo Dagba, Marigbo; W; [FC = 7, RFC = 0.12, N_{UR} = 17, CII = 0.28]	Leaves	1. Consumption of the vegetable is recommended for pregnant women to aid in easing delivery 2. Dried leaves are ground with some non-plant materials and used to make incisions at the joints on the body to prevent rheumatism

Note: Species are written alphabetically according to their family names with author citation followed by the vernacular (Yoruba) names of the plants and the plant's source. *CW* Cultivated and Wild, *W* Wild

Common method of use includes topical application, direct consumption, and maceration; the use of *Clerodendrum volubile* for rheumatism involves its application through incision marks. Apart from the marks, the highest percentage of use is in the form of eating either the cooked or the raw vegetable (35%) followed by maceration (30%). The vegetables were also used as leaf juice (20%), decoctions (10%), and leaf paste (5%). At least 50% of the vegetables recorded in the field are used to treat no less than two ailments. The highest use rate was obtained with *Vernonia amygdalina* being used to treat four ailments.

6.3.2 Medicinal Use Review

The medicinal uses have been classified into nine (9) broad categories—namely, respiratory problems, reproductive problems, urinary tract infections/problems (UTIs), circulatory problems, degenerative diseases, nervous system disorders, wound healing and skin inflammations, digestive ailments, and others—according to Moteetee et al. (2018). A list of ILVs used in healthcare management by the five communities in Osun State, as well as their reported medicinal uses/potential medicinal uses, is provided in Table 6.3. Included are their vernacular names, reported uses, and references.

Table 6.3 List of ILVs used in health management

Species Family	Vernacular names (Yoruba)	Main use(s)	References
Celosia argentea Amaranthaceae	Soko	RespP, RepP, DegD, WHSI, DigA & OA	Kanu et al. (2019); Hamzah et al. (2018); Ashok et al. (2013); Varadharaj and Muniyappan (2017); Stuart (2016)
Celosia trigyna Amaranthaceae	Ajefowo	RepP, UTIs, CP, DegD, WHSI & DigA	Eboh et al. (2019); Bayala et al. (2020); Bello et al. (2020)
Clerodendrum volubile Verbenaceae	Efo dagba Marigbo	RepP, CP, DegD, NSD, WHSI, DigA & OA	Erukainure et al. (2018)
Colocasia esculenta Araceae	Omunu koko	RespP, DegD, NSD, WHSI, & OA	Prajapati et al. (2011); Amit et al. (2019); Reyad-ul-Ferdous et al. (2015); Patil and Ageely (2011)
Corchorus olitorius Malvaceae	Ewedu	RepP, UTIs, CP, DegD, NSD, DigA & OA	Adedosu et al. (2015); Adebo et al. (2018); Ashok et al. (2020); Ismail et al. (2018); Nyadanu et al. (2017)
Crassocephalum crepidioides Asteraceae	Ebolo	DegD, NSD, WHSI, DigA & OA	Akinpelu et al. (2019); Adedayo et al. (2015); Akakpo and Achigan-Dako (2019); Bahar et al. (2017); Thomford et al. (2012); Sakpere et al. (2013)
Cucurbita pepo Cucurbitaceae	Elegede	NSD & OA	Arowosegbe et al. (2015)
Launea taraxacifolia Asteraceae	Yanrin	DegD, CP, WHSI & OA	Adinortey et al. (2018); Adewale et al. (2020); Akakpo and Achigan-Dako (2019)
Solanecio biafrae Asteraceae	Woorowo	RespP, RepP, CP, DegD, NSD, WHSI, DigA & OA	Bello et al. (2018); Olaniyan et al. (2020); Olaniyan (2019)
Solanum nigrum Solanaceae	Odu	RespP, RepP, DegD, WHSI, DigA & OA	Agoreyo et al. (2017); Ogunsuyi et al. (2018); Bello et al. (2020); Hadi et al. (2017)
Talinum triangulare Portulacaceae	Gbure	UTIs, CP, DegD, WHSI DigA & OA	Aja et al. (2010); Soladoye et al. (2013); Ogunlesi et al. (2010); Airaodion et al. (2019); Liang et al. (2011)
Vernonia amygdalina Asteraceae	Ewuro	RespP, DegD, WHSI, DigA & OA	Bayala et al. (2020); Akakpo and Achigan-Dako (2019)

Key: *RespP* Respiratory problems, *RepP* Reproductive problems, *UTIs* Urinary tract infections, *CP* Circulatory problems, *DegD* Degenerative diseases, *NSD* Nervous system disorders, *WHSI* Wound healing and skin inflammations, *DigA* Digestive ailments, *OA* Other ailments

6.3.2.1 Respiratory Problems

The leaves of *Solanum nigrum* have been reported to be used in the treatment of tuberculosis. The decoction of the berries and flowers are useful in treating cough and are remedies for pulmonary tuberculosis and bronchitis (Hadi et al. 2017). *Colocasia esculenta* leaves and extract from the leaves and root of *Talinum triangulare* can be employed in treating asthma (Ogie-Odia and Oluowo 2009; Hadi et al. 2017).

Bello et al. (2018) reported that *Solanecio biafrae* is used in the treatment of cold and the leaves of *V. amygdalina* are used in treating cough and cold (Akakpo and Achigan-Dako 2019). The seeds of *Celosia argentea* are used for the treatment of epistaxis (Ashok et al. 2013) and cough (Nidavani et al. 2013). In the study areas covered in Osun State, however, only *Solanecio biafrae* and *V. amygdalina* are used in treating respiratory problems. Table 6.4 includes data from the Yoruba people in Osun State, Nigeria, as encountered in the field. *Vernonia amygdalina* was the only vegetable Kayode et al. (2020) reported for the treatment of respiratory problems in Ekiti State, Nigeria. This could be because of a lack of additional information available to the inhabitants of these study areas or the fact that, as reported by Kayode et al. (2020), in the consumption of these vegetables, emphasis is placed on prevention rather than cure.

6.3.2.2 Reproductive Problems

The plants used in this category include *Celosia trigyna, Clerodendrum volubile* and *Solanum nigrum*. *Celosia trigyna* is included in several medicinal preparations used to treat women's disorder and diseases, including ovarian troubles in DR Congo and excessive menstruation in Ethiopia (Eboh et al. 2019). *Clerodendrum volubile* on the other hand is reported to be used as an anti-abortifacient (Adefegha and Oboh 2016; Ajao et al. 2018) while the aqueous extract of *Solanum nigrum* has been proposed by Agoreyo et al. (2017) for the management of preterm contraction in pregnant women.

The whole plant of *Celosia argentea* is used for treating gonorrhea (Stuart 2016) and the seeds are prescribed for haemorrhagic conditions including menorrhagia. In U.S. midwifery, it is a common rural *Honduras* practice to recommend *C. argentea* for increased lactation for nursing mothers (Nidavani et al. 2013) while the seed paste is used to cure ovarian and uterine diseases in India. Low sperm count, female infertility, and painful menstruation are all reported to be treated with *S. biafrae* (Bello et al. 2018), which is also a botanical galactagogue. Used in association with *Eremomastax speciosa* (Hochst.) Cufod., it is also reported by Bello et al. (2018) to have the ability to precisely act on the normalization of the menstrual cycle by inducing ovarian folliculogenesis.

The leaves of *Corchorus olitorius* are used in ethnomedical practices to treat gonorrhea and is cited as the main element of some remedies for female infertility (Adedosu et al. 2015; Adebo et al. 2018; Ashok et al. 2020). Only *Corchorus*

Table 6.4 Uses of ILVs in health management

Species	Local name	Part(s) used	RespP	RepP	UTIs	CP	DegD	NSD	WHSI	DigA	OA
Celosia argentea	Soko	Leaf									Hemorrhoid
Celosia trigyna	Ajefowo	Leaf							Eczema		
Clerodendrum volubile	Efo dagba Marigbo	Leaf		Difficult labor			Rheumatism				
Colocasia esculenta	Omunu koko	Leaf							Dandruff		
Corchorus olitorius	Ewedu	Leaf		Difficult labor					Measles		
Crassocephalum crepidioides	Ebolo	Leaf									Snake bites
Cucurbita pepo	Elegede	Leaf							Rashes		
Launea taraxacifolia	Yanrin	Leaf					Diabetes			Constipation	
Solanecio biafrae	Woorowo	Leaf	Cough								
Solanum nigrum	Odu	Leaf								Stomach upset	Snake bites
Talinum triangulare	Gbure	Leaf				Anemia			Boil		
Vernonia amygdalina	Ewuro	Leaf	Epistaxis				Diabetes				Hemorrhoid, pile and measles

Key: *RespP* Respiratory problems, *RepP* Reproductive problems, *UTIs* Urinary tract infections, *CP* Circulatory problems, *DegD* Degenerative diseases, *NSD* Nervous system disorders, *WHSI* Wound healing and skin inflammations, *DigA* Digestive ailments, *OA* Other ailments *olitorius* and *Clerodendrum volubile* were encountered in the field in the study areas with regard to reproductive problems (see Tables 6.2 and 6.4). *C. olitorius* was also consistently reported to be used in treating various reproductive issues in Ekiti State (Kayode et al. 2020).

6.3.2.3 Urinary Tract Related Problems

None of the vegetables encountered in the field were recorded to be used in the treatment of urinary tract problems. In literature, however, *Celosia* species, *Talinum triangulare*, *Cucurbita pepo*, and *Corchorus olitorius* have been reported to be employed traditionally or to be potential candidates in the treatment of urinary tract related problems.

Eboh et al. (2019) reported that extract of *Celosia trigyna inhibited* xanthine oxidase (XO) activity in a dose-dependent manner and shows chelating properties against Fe^{2+}. In their opinion, *Celosia trigyna* could be explored for the prevention and management of hyperuricaemia (excess uric acid in the blood) conditions. Sharma and Lamichhane (2017) reported that boiled extract of *Celosia argentea* root is taken as an anti-urolithiatic. The seed of *C. pepo* is also used in prevention of kidney stones (Arowosegbe et al. 2015); the leaves of *C. olitorius* and *Talinum triangulare* possess anti-oxidants compounds in abundance, which is associated with various biological properties including diuretic activities (Ashok et al. 2020; Ikewuchi et al. 2017). Apart from being a diuretic, according to traditional medicine, the leaves of *T. triangulare* are used to treat polyuria (Swarna and Ramalingam 2013).

6.3.2.4 Circulatory-Related Problems

Celosia trigyna is employed in Africa to manage heart complaints (Bello et al. 2020). Several vegetables have been reported to be used or promising in the treatment and management of hypertension, pulmonary defects, and other cardioprotective functions, including *Clerodendrum volubile* leaf (Adefegha and Oboh 2016; Erukainure et al. 2018; Olorundare et al. 2020), *Vernonia amygdalina* (Akakpo and Achigan-Dako 2019), *Launaea taraxacifolia* (Adinortey et al. 2018), *S. biafrae* (Bello et al. 2018; Olaniyan et al. 2020; Olorundare et al. 2020), *C. pepo* (Arowosegbe et al. 2015), *Talinum triangulare* (Swarna and Ramalingam 2013; Ikewuchi et al. 2017), and *C. olitorius* (Adebo et al. 2018; Ashok et al. 2020).

In DOX-induced cardiotoxicity, *Clerodendrum volubile* extract has been reported to offer protection mediated through free radical-scavenging activity/anti-oxidant mechanism, and it reduces the risk of cardiovascular disease (Olorundare et al. 2020). Only *Talinum triangulare*, being used to treat anemia, was encountered in the field with regard to circulatory problems.

6.3.3 Degenerative Diseases/Nervous System Disorders

The leaves of *Solanum nigrum* are used as poultice for rheumatic and gouty joints (Hadi et al. 2017). According to Atanu et al. (2011), the extracts of *Solanum nigrum* induces apoptosis in hepatoma cells via two distinct anti-neoplastic activities of the extract, suggesting that it may be used in the treatment of liver cancer. Leaf extracts of *Celosia trigyna* also have been reported to be potentially cytotoxic to HeLa cell lines in the treatment of cervical cancer, whereas water-soluble leaf extracts of *Vernonia amygdalina* was found to inhibit DNA synthesis of MCF-7 cells (breast cancer) (Bayala et al. 2020). They reported that, if *Vernonia amygdalina* is incorporated into the diet, it may prevent or delay the onset of breast cancer. Eating *Colocasia esculenta* has also been reported to be good in lessening the risk of colon cancer (Amit et al. 2019). *L. taraxacifolia* has exhibited a significant growth inhibitory effect on esophageal WHC01 cancer cells (Thomford et al. 2016).

Neurodegenerative diseases may be caused by viral infections, and Javed et al. (2011) have shown that methanolic and chloroform extract of *Solanum nigrum* seeds is involved in viral clearance during natural Hepatitis C Virus (HCV) infection. In the study, they directed the chloroform extract against HCV NS3 and observed a specific inhibition of NS3 protease in a dose-dependent manner, while GAPDH mRNA (internal control) stayed constant. Their data suggested an alternative approach to the treatment of chronic HCV infection through therapeutic induction of extracts, which could lead to the development of a more effective oral HCV drug.

The therapeutic use of *Solanum nigrum* in the Unani traditional systems for the treatment of hepatitis also has been reported (Bashir 2019). *Solanum nigrum* seeds may find a use in the prevention and treatment of COVID-19, which is also a viral infection, seeing that it is also used in the treatment of tuberculosis, which affects the lungs. Dasgupta et al. (2016) also reported that the daily consumption or frequent intake of the leaf of *Solanum nigrum* could serve as an adjuvant in streamlining diabetes (one of the underlying factors that exacerbates the effect of COVID-19). Data generated by Adefegha and Oboh (2016) also shows that *Clerodendrum volubile* leaf is a promising natural alternative in the management of non-insulin dependent diabetes mellitus (NIDDM). The therapeutic effect of *C. volubile* leaves against type II diabetes has also been reported (Erukainure et al. 2018). This vegetable is employed in the treatment of rheumatism, while *Vernonia amygdalina* and *Launaea taraxacifolia* are used in treating diabetes in the study area.

Dietary inclusions of *Solanum* leaf as a source of functional foods could serve in the prevention and management of neurodegenerative disease, protecting against cognitive and neurochemical impairments induced by scopolamine—for example, Alzheimer's disease (Ogunsuyi et al. 2018; Campisi et al. 2019). Still, for *Clerodendrum volubile*, Oboh et al. (2017) believed that in vitro and clinical investigations are required to ascertain the use of this vegetable or its extract(s) in the management of Alzheimer's disease and Parkinson's disease.

Leaves of *S. biafrae* contain various secondary metabolites (e.g., dihydroisocoumarins, terpenoids, and sesquiterpenes), which are used as a rheumatic pain reliever among other problems. Eating the leaves of *Crassocephalum crepidioides* daily has also been reported to treat rheumatism (Akakpo and Achigan-Dako 2019) and Alzheimer's disease (Adedayo et al. 2015). The vegetable is reported to possess anti-tumor activity (Akinpelu et al. 2019). Akinpelu et al. (2019) reported that consumption of *C. crepidioides* leaf in cooked form has more medicinal value and that both cold water and hot water extracts can cause cellular damage at high doses. Nevertheless, according to Adedayo et al. (2015), blanching causes a reduction in the anti-oxidant and anticholinesterase properties of *C. crepidioides*. To maximize the nutraceutical values of the vegetable moderate/mild heat may be required during cooking (Adedayo et al. 2015).

Other vegetables reported for treating cancers, arthritis, diabetics, and some age-related diseases include *Talinum triangulare* (Swarna and Ramalingam 2013; Xu et al. 2015), *Launaea taraxacifolia* (Adinortey et al. 2018), *C. olitorius* (Ismail et al. 2018), and *Colocasia esculenta* (Prajapati et al. 2011; Reyad-ul-Ferdous et al. 2015).

Celosia trigyna leave pulp is reported to be used to treat pains (e.g., back, chest, and costal) and against stomachache (Bello et al. 2020). Among other uses, the leaves of *Solanum nigrum* are used in the treatment of nervous disorders (Hadi et al. 2017). *Crassocephalum crepidioides* is used to treat epilepsy (Bahar et al. 2017) and *S. biafrae* is used as a rheumatic pain reliever (Bello et al. 2018). *Colocasia esculenta* leaves have been used for treatment of neurological disorders and particular attention has been given to analgesic and hypolipidemic effects (Prajapati et al. 2011).

6.3.4 Digestive Ailments

The leaves and flowers of *C. trigyna* are employed against diarrhea (Eboh et al. 2019), and the leaf pulp is used against stomachache. *Solanum nigrum* as a medicinal plant is used as an anti-ulcerogenic; in China, its chemo preventive ability is held in high esteem and is used to manage cancers related to the digestive system (Bello et al. 2020).

Celosia trigyna also has been reported to be effective in the management of gastric ulcers. It has shown inhibitory activity against a-chymotrypsin with DCM and hexane showing maximum inhibitory activity, which was comparable to chymostatin (positive control). Chondrillasterol, lutein, pheophytin A, and chondrillasterol acetate were isolated from *C. trigyna* and showed the percentage inhibition of chymotrypsin (protease) in increasing order of lutein > chondrillasterol acetate > chondrillasterol > pheophytin A (Ofusori et al. 2020). These authors reported that anti-ulcerogenic effects have been related to protease inhibition and that the isolated compounds are possibly responsible.

Celosia argentea leaves are used to relieve gastrointestinal disorders (Kanu et al. 2019; Stuart 2016). Its seeds, when in decoction or finely powdered, are considered anti-diarrhoeal though the root is used for abdominal colic (Stuart 2016). To scientifically appraise some of the ethno-medical uses of *Celosia argentea*, Sharma et al. (2010) examined the anti-diarrhoeal properties of alcoholic extract of *Celosia argentea* leaves. The result produced a dose-dependent anti-diarrhoeal effect, suggesting that it may act to inhibit PGE2 to give anti-diarrhoeal effects.

Talinum triangulare is used for the management of gastrointestinal disorders (Ikewuchi et al. 2017) and *C. crepidioides* is used to treat indigestion and stomachache (Bahar et al. 2017).

6.3.5 Wound Healing, Skin Inflammations, and Other Ailments

Bello et al. (2020) reported that compounds like chondrillasterol, chondrillasterol acetate, pheophytin A, and lutein, which exhibit antiulcer, anti-oxidant, anti-diuretic, against heart diseases have been isolated from *C. trigyna*. In a review by Chauhan et al. (2012), glycoalkaloids, glycoproteins, polysaccharides, polyphenolic compounds (e.g., gallic acid, catechin, protocatechuic acid, caffeic acid, epicatechin, and rutin) were reported as the chemical constituents commonly found in *Solanum nigrum*. These compounds, they reported, contribute to various biological activities (e.g., anti-bacterial, anti-fungal, anti-inflammatory, anticancer, anti-oxidant, anti-pyretic, and cytotoxic).

Although Chauhan et al. (2012) reported that only root, whole plant, and leaves are used for medicinal purposes, even though the black fruits are toxic, Hadi et al. (2017) affirm that juice of the fruits are used as an anti-diarrhoeal, ophthalmopathy, hydrophobia, and in treating heart disease. They are also useful for inflammations and skin diseases. Solanine, a glycoalkaloid, is present in high concentrations in most parts of *Solanum nigrum* with the highest levels found in unripe berries. Yet, the ripe berries are the least toxic part of the plant and are sometimes eaten without harmful effects (Atanu et al. 2011).

According to Adebo et al. (2018), *C. olitorius* is commonly used for treating malaria, while Bashir (2019) reported the use of *Solanum nigrum* in the treatment of eye, ear, and nose diseases. Senjobi et al. (2017) reported that the methanol leaf extract of *Clerodendrum volubile* has analgesic potential, thus validating its traditional use in pain management.

Talinum triangulare is used to treat shistosomiasis, scabies, and fresh cuts (Ikewuchi et al. 2017). The stems of *L. taraxacifolia* are taken to improve appetite during illness, and the leaves are used to treat fevers. The stems of *V. amygdalina* are used as toothbrushes, but also against ailments—for example, gastric disorders (stomach pain, angina, nausea, diarrhea, and bad breath) (Akakpo and Achigan-Dako 2019). The roots and leaves of *Celosia trigyna* can be used in the treatment of wounds and skin problems, while other *Celosia* species (e.g., *Celosia argentea*) have been reported to improve wound healing in a rat burn model (Ofusori et al. 2020).

According to Bello et al. (2020), *C. trigyna* is used to manage pustular skin eruptions, while *Solanum nigrum* is used as an anti-inflammatory agent. *Solanum nigrum* is reported to be a traditional European medicine for cooling infirmities. It was considered good for cooling hot inflammations, ringworms, ulcers, testicular swellings, gout, and ear pain. It also has been used in the treatment of convulsions. The Arabs use its crushed fresh leaves to relieve pain, as a poultice for skin diseases, and inflammation reduction (Hadi et al. 2017; Bello et al. 2020). The dried leaf powder of *C. crepidioides* is used as a snuff to stop nose bleeds in Tanzania and is smoked to treat sleeping sickness. *Crassocephalum crepidioides* is also used to treat headaches and fresh wounds (Sakpere et al. 2013).

Nanoparticles, made from *C. trigyna* and *S. nigrum* (i.e., CT-AgNPs, SN-AgNPs) and extracts of *C. trigyna* and *S. nigrum*, exhibited some lipoxygenase activity and therefore possess a significant inhibition towards inflammation (Bello et al. 2020). They, however, submitted that the extracts from these wild vegetables and their corresponding nanoparticles need further employment of in vivo activity to fully validate their anti-oxidant and anti-inflammatory activities.

6.4 Conclusion

Vegetables are rich and inexpensive sources of nutrients, especially in Africa where starchy, staple food is the main diet. They contribute to protein, minerals, macro- and micro-nutrient supply in diets. Consequently, the World Health Organization (WHO) recommend an intake of 5–8 portions of fruits and vegetables (400–600 g) daily to reduce the risk of deficiencies and diseases, which include micro-nutrient deficiency, cardiovascular disease, cancer, cognitive impairment, and other nutritional health risks.

The U.S. Department of Agriculture and the U.S. Department of Health and Human Services (2010) dietary guidelines recommend that to obtain the optimum daily allowance of Cu, 100 g of *C. volubile* should be consumed and 400 g daily for optimum Mn intake. For children (9–13 years) 100 g of *C. volubile* can supply the vitamin C requirement; however, that of adults can be met by a daily intake of 400 g of *S. biafrae* or 200 g of *C. volubile*. To obtain the recommended daily allowance of Cu, Fe, and Zn (for females) and that of Mn, 100 g of *S. biafrae* should be consumed (Sakpere et al. 2015).

The literature survey on the various ILVs has revealed that they have high medicinal value and the study has given justification to the traditional uses of plants by the indigenous communities in Osun State. According to clinical and epidemiological research, 80% or more of current chronic ailments and premature deaths can be prevented with changes in diet and lifestyle (Maeda 2013).

In a country, where affordability and access to quality medicines is a major challenge, there is a need to aim at preventing diseases by eating right and treating food as medicine. This review brings to light the fact that ILVs are a potential source of natural phenolic anti-oxidants, which can be used as functional foods for the prevention and management of different health challenges, especially neurodegenerative diseases.

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Chapter 7
Combined Application of Subsurface Drainage and Fertilization, a Method to Reduce the Effects of Iron and Sulfide Toxicities in Irrigated Rice Fields in Burkina Faso

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7.1 Introduction

Since the first recording of occurrence (Ponnamperuma et al. 1955), rice iron toxicity is reported worldwide, particularly in Asia, South America, and West and Central Africa (Becker and Asch 2005; Balasubramanian et al. 2007; Fageria et al. 2008). Iron toxicity is one of the major soil stress factors in West Africa (Gridley et al. 2006; Olaleye et al. 2009; Barry et al. 2019). Indeed, about 19% of Africa's total rice area is at a high risk of iron toxicity (Haefele et al. 2014). Iron stress affects 55% of the rice area in three West African countries (Guinea, Ivory Coast, and Ghana), and 10% of this area remains unusable due to the severity of the stress (Engel et al. 2012; Sikirou et al. 2015).

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In Burkina Faso, many rice fields are affected by iron and sulfide toxicities. For example, since 1986, over 300 ha of rice fields are abandoned in Kou Valley. In many irrigation schemes, such as Moussodougou, Tiéfora, and Kou Valley, the stagnation or even the drop in yield persists in many areas, despite major efforts in terms of fertilization, phytosanitary treatments, and varietal selection.

To overcome iron and sulfide toxicities in paddy fields, many types of research were conducted on the selection of resistant rice varieties. However, out of the 60 varieties of NERICA rice tested in plots of producers in 20 sub-Saharan countries including Burkina Faso, no variety showed clear resistance to iron toxicity (Somado et al. 2008). Certain varieties were rejected by producers because of their sensitivity to iron toxicity.

Studies showed that Iron-Reducing Bacteria (IRB) and Sulfate-Reducing Bacteria (SRB) are the main microorganisms producing ferrous ions and sulfides in rice fields (Jacq 1989; Yi et al. 2012). Moreover, soils mineral fertilizers application seems to permit the rice plant to resist the penetration of toxic ions (Becker and Asch 2005; Panda et al. 2012; Shahid et al. 2014). Likewise, deep and regular soil drainage is recommended to avoid the accumulation of the toxic ions in rice (Audebert 2006).

After decades of research in the fight against ferrous and sulfide toxicities, through the varietal selection and fertilization methods, the constraints remain and reduce the productivity of rice in the irrigated areas. The constraints persist to this day because the studies are probably carried out separately in general.

The present research is a holistic approach integrating the dynamics and the activities of the IRB and SRB, the subsurface drainage, a choice of resistant varieties, and an adequate fertilization mode. This approach should permit a sustainable reduction and control of these constraints to improve rice productivity.

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7.2 Iron and Sulfide Toxicities in Rice Fields

Iron is one of the essential chemical elements for the rice plants to grow (Onyango et al. 2019). However, a high iron content in the soil leads to a nutritional disorder at the plant level (Morrissey and Guerinot 2010).

In West Africa, iron toxicity is one of the most widespread edaphic stresses hampering rice plant growth (Sikirou et al. 2015). Iron toxicity happens when high contents of iron (Fe^{2+}) and sulfide (Ponnamperuma 1972; Sahrawat and Diatta 1996; Ethan and Odunze 2011) are drained and accumulated in the lowland soil solution. Iron and sulfide toxicities can be issued from the in situ microbial reductions of ferric iron (Ethan and Odunze 2011) and sulfate (Liesack et al. 2000). These phenomena can arise from leaching and runoff of water along adjacent slopes (ADRAO 2002).

Indeed, under the reducing effect of the environment, some bacteria, such as IRB and SRB can set up anaerobic respiration leading to the dissolution of large quantities of ferrous ions (Fe^{2+}) (Liesack et al. 2000; Luef et al. 2013). Iron toxicity can affect all types of waterlogged rice fields with or without water control (Audebert 2006).

Thus, iron toxicity occurs in mangroves, irrigated lowlands, and rainfed areas when Fe^{3+} (insoluble form of iron) in the soil is reduced to Fe^{2+} (soluble form) under anaerobic conditions and low pH (Jose and Fett 2014).

The ferrous and sulfide ions can lead to an imbalance of the mineral component of the soil solution, which could affect the rice plant growth (Liesack et al. 2000; Shahid et al. 2014).

Moreover, iron and sulfide toxicities result in the appearance of leaf bronzing or yellowing symptoms, rice growth decreasing, and panicle sterility rate increasing (Onyango et al. 2019). Rice productivity can drop by up to 100% according to the soil ferrous ions content and the rice variety's ability to resist (Chérif et al. 2009).

7.3 Microorganisms Implication in the Appearance of Iron and Sulfide Toxicities in Rice Fields

IRB and SRB contribute to iron and sulfide toxicities in rice fields (Stubner and Meuser 2000; Hori et al. 2010). Generally anaerobic, the IRB and SRB are heterogeneous groups of prokaryotes, which by their metabolism operate respectively the dissimilatory reduction of iron and sulfate in the soil coupled with the oxidation of the organic compounds in submerged soils (Munch and Ottow 1983; Bousserrhine et al. 1999; Ehrlich 2002).

Thus, the reduction processes begin in waterlogged soils, few days after flooding; oxygen is firstly depleted in the soil compartments by aerobic microorganisms during oxidation reactions (Liesack et al. 2000). The other electron acceptors (Mn (IV), Fe (III), sulfate) are later used within days by facultative anaerobic and strict anaerobic microorganisms to reduce oxidized soil compounds such as nitrate (Ratering and Schnell 2000; Scheid et al. 2004). Excessive absorption of Fe^{2+} and

H_2S^- produced during the process by the roots of the rice and their accumulation in the leaves allow the appearance of the symptoms of bronzing and yellowing in rice plants (Chérif et al. 2009; Engel et al. 2012).

7.3.1 Iron-Reducing Bacteria Ecology in Rice Paddy Soils

In rice fields, iron reduction begins immediately after submersion of soils, at the water–soil compartment, and in the rhizosphere (Ponnamperuma 1972; Patrick and Reddy 1978; Coonrad and Frenzel 2002; Conrad 2007).

A very wide variety of aerobic, strictly anaerobic, or facultative anaerobic microorganisms can reduce iron in anaerobic conditions. However, all members of IRB populations present in the rhizosphere are not exhaustively established and are poorly documented (Hori et al. 2010). The bacteria belonged to Clostridium, Bacillus, Geobacter, Pelobacter, Cytophaga, Flavobacterium, and Bacteroides genera, while *Ferribacterium limneticum* and Anaeromyxobacter spp. species were identified as the predominant IRB populations in several rice soils (Scheid et al. 2004; Hori et al. 2010).

Ouattara and Jacq (1992) identified fermentative bacteria (Anaerovibrio and Clostridium) as dominant groups of IRB in the Kou Valley lowland in Burkina Faso. Bongou-Devisme et al. (2014) identified also the bacterial species Bacillus sp., and Enterobacter sp., in the Ivory Coast rice fields.

7.3.2 Sulfate-Reducing Bacteria in Rice Paddy Soils

Sulfate-reduction process is responsible for almost all of the sulfides produced in the submerged rice fields (Liu et al. 2009). This phenomenon is frequently observed in the paddy field (Jacq 1973; Liesack et al. 2000). The SRB are present in the soils of rice fields where the sulfides produced by their activity can be lethal for the rice plants (Jacq 1989). Nowadays, the microbial processes of sulfate reduction in the flooded rice paddy soils ecosystem are well known.

Rice fields are hydromorphic environments, where oxygen deficit is prolonged due to temporary or permanent saturation of the soil's pores by water (Liesack et al. 2000). Rice field soils are complex systems composed of three compartments, namely, rhizosphere, and oxic and anoxic zones (Liesack et al. 2000). Each compartment is distinguished from the others by physicochemical properties, metabolism, and composition of the active microbial communities (Liesack et al. 2000; Ratering and Schnell 2000).

As soon as the paddy field submerges, the soil oxygen is rapidly consumed by aerobic bacteria (Ponnamperuma 1981). Furthermore, anaerobic microflora begin denitrification, iron and sulfate reduction, and methanogenesis, which are the final steps in the degradation of organic compounds (Ponnamperuma 1981; Achtnich et al. 1995a, b; Garcia et al. 2000).

However, Wind et al. (1999) and Liesack et al. (2000) showed high rates of sulfides production and wide SRB communities in the rice rhizosphere, where rice plant releases a high quantity of oxygen in the flooded soils. Indeed, the rice plant provides through the roots, exudates that are used by SRB as electron donors, stimulating their growth (Jacq 1989; Lin and You 1989).

In West Africa, Ouattara and Jacq (1992) identified Sulfate-Reducing Bacteria very close to Desulfovibrio, as dominant groups of SRB in the Kou Valley lowland in Burkina Faso. Dianou et al. (1998) also identified an SRB close to *Desulfovibrio desulfuricans* in Burkina Faso rice fields' soils. Moreover, Bongoua-Devisme (2009) identified the bacterial species *Desulfovribrio desulfuricans*, and Enterobacter sp., in the Ivory Coast rice fields.

SRB belonging to delta-Proteobacteria subdivision can proceed to iron dissimilatory reduction (Zhang et al. 1999; Waite et al. 2020). However, these SRB are not able to survive using Fe^{3+} as single electron acceptor (Lovley et al. 1993; Wunder et al. 2021). Therefore, many studies showed the implication of *Desulfovibrio desulfuricans* in the ferric iron reduction process in West Africa, in sensitive rice fields (Ouattara and Jacq 1992; Dianou et al. 1998; Bongoua-Devisme 2009).

7.4 Symptoms of Rice Iron and Sulfide Toxicities

Iron and sulfide toxicities are defined as nutritional diseases appearing in rice fields under submerged soil when high content of ferrous ions and sulfides are produced (Becker and Asch 2005; Quinet et al. 2012). It is difficult to make the difference between sulfide and ferrous ion toxicities in the field, as the two stresses are usually linked (Park and Tanaka 1968). The exact diagnosis of sulfide toxicity is often difficult (except when high levels are measured) because the significant manifestations may be hidden by other symptoms (Freney et al. 1982). However, the deleterious effects of sulfides and ferrous ions at the plant level have been widely discussed by Freney et al. (1982).

7.4.1 Symptoms of Rice Iron Toxicity

Iron toxicity symptoms usually appear on the leaves of rice plants and on the soil surface. Indeed, when the soil is flooded for a long time in the rice fields containing high iron II (Fe^{2+}) content, a reddish-brown coloration appears on the soil surface (iron oxide film), scum appears on the surface of standing water (Fig. 7.1) and/or reddish oily water oozes out of the soil (ADRAO 2006).

Concerning the rice plant, two main types of symptoms can be observed on the leaves. The symptoms of "browning" or "bronzing" of rice leaves are typical visual manifestations associated with high concentrations of ferrous ions (Fe^{2+}) in rice leaves, resulting from the production of oxidized polyphenols (IRRI 2002; Becker and Asch 2005). Bronzing disease results in the appearance of reddish-brown spots on the lower leaves (Chérif et al. 2009). The leaves turn brown, then dark gray, and

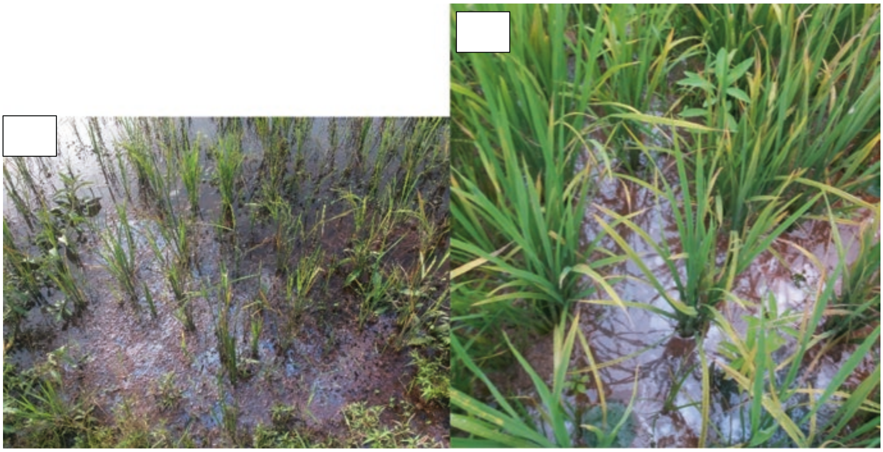

Fig. 7.1 Illustration of iron toxicity symptoms on soil and rice plants in the Kou Valley, Burkina Faso. (**a**, **b**) Appearance of ferric oxide (red color) on the surface of the water (**a**) Growth of rice plants is delayed

die as the spots expand (Becker and Asch 2005; ADRAO 2006). The second symptom is "orange disease"; it appears on the lower leaves, beginning at the tip of the leaves and advancing toward the base (Becker and Asch 2005; ADRAO 2006).

Symptoms of iron toxicity can occur early or late at different stages of rice growth. Indeed, when it occurs during germination, the germination of rice grains is delayed and/or stopped. Iron toxicity occurring early at the seedling stage is called primary toxicity (Becker and Asch 2005; ADRAO 2006). A slowing down of the development of rice plants, reduced tillering, and a yield decrease (ADRAO 2006; Panda et al. 2012) characterize it.

Secondary iron toxicity is described as occurring at the end of the vegetative phase or beginning of the reproductive phase (Singh et al. 1992). It results in dry matter decreasing, reduction in plant height, and the reduction in the number of panicles (Sahrawat 2010; Panda et al. 2012). Secondary iron toxicity is responsible for the sterility of spikelets, flowering and maturation stages are delayed by about 20–25 days, (Audebert and Sahrawat 2000; Sahrawat 2010) reducing the crops yields (Becker and Asch 2005). At this stage, root growth stops, the aerenchymas age and become damaged. Moreover, the oxidizing power of the roots is strongly decreased; their surface is covered with a blackish precipitate of FeS produced in the soil, which leads to the degeneration of the roots. (Becker and Asch 2005).

7.4.2 Sulfide Toxicity for Rice Plant

When high content of sulfides occurs in rice paddy fields, some enzymes of the plant located in the roots such as cellulases, peroxidases, ascorbate oxidases, and polyphenol oxidases are inactivated (Allam and Hollis 1972; Armstrong and

Armstrong 2005). Furthermore, root respiration is blocked (Ota 1968; Dobermann and Fairhurst 2000), the oxidizing power of the roots is greatly reduced (Takijima 1965; Tanaka et al. 1968; Allam and Hollis 1972) and the regulation of toxic ions in the cells of roots, like Fe^{2+}, is canceled (Park and Tanaka 1968). Sulfide toxicity can result in the formation of a FeS hemi-permeable membrane near the root (Armstrong and Armstrong 2005). This membrane allows the passage of water but prevents the passage of ions limiting the mineral nutrition of the plant (Jacq 1989).

Jacq (1973, 1975) described the symptoms of sulfides in rice fields. Thus, rhizospheric sulfate-reduction results in very rapid wilting of the leaves (particularly the peripheral and older leaves) followed by browning. The browning progresses from the top of the leaf towards the stem. As soon as symptoms appear, the rhizosphere soil should be analyzed to confirm the high level of ferrous sulfides. The sulfide toxicity leads rice plants to be susceptible to physiological diseases (Hollis et al. 1975). Indeed, in mild forms of sulfide toxicity, the symptoms described above are often obscured by the simultaneous onset of other physiological diseases such as iron toxicity, Helminthosporium attack and pathogenic fungi (Baba 1958; Wamishe et al. 2018).

The tillering is generally reduced and the growth is slowed down or even completely stopped at the beginning of the rice biological cycle ("primary" toxicity). Sulfide toxicity occurring at the end of the rice crop cycle ("secondary" toxicity) can induce yield reduction of the order of 30–50% (Baba 1958; Wamishe et al. 2018).

7.4.3 Mechanisms of Iron and Sulfide Toxicities Induction in the Rice Plant

Rice plants can absorb a significant amount of iron compared to most plants; however, Fe^{2+} is the predominant form of iron in paddy fields. Sulfide ions from SRB metabolism damage root cortices (Inada 1965a, b; Allam and Hollis 1972) and promote iron ion uptake. Fe^{2+} enters rice by root uptake and attains the xylem through the symplastic passage of the Caspari band (Na and Salt 2011; Wu et al. 2014). In the xylem Fe^{2+} tracks the plant transpiration flux. Inside the cell, the excessive amounts of Fe^{2+} can induce the production of harmful molecules such as superoxide, hydroxyl radical, H_2O_2 and perferryl radicals (Peterson 1991). Iron ion can react with fatty acids, and produces form peroxidized fatty acids (Peterson 1991). The chemical compounds resulting from the process (free radicals) are responsible for irreversible damages associated with iron stress (Thongbai and Goodman 2000). The harmful molecules produced can irreversibly damage rice plant cell membrane structures, nucleic acids, and affect membrane charge (Becker and Asch 2005). Moreover, the content of polyphenols increases in the cell (Yamauchi and Peng 1993) and the free radicals produced can lead to the oxidation of chlorophyll inducing a reduction of chlorophyll concentration in the plant (Monteiro and Winterbourn 1988). Thus, ferrous and sulfurous toxicities result in growth difficulties, a loss of plant biomass, and yield losses ranging from 10% to 100% depending on the severity of the constraints.

7.5 Usual Methods to Reduce Iron and Sulfide Toxicities in Rice Fields

Besides their involvement in some physiological diseases of the rice plant, SRB and IRB through their activities are responsible for metallic biocorrosion and some human diseases, inducing major economic constraints (Posgate 1984). Thus, it is important to find strategies to reduce the deleterious effect resulting from the metabolism of these bacteria in the ecosystem. Several methods are available for this purpose.

7.5.1 Chemical Methods to Reduce Sulfide Toxicities in Rice Fields

Besides their implication in the occurrence of iron and sulfide toxicities in rice fields, SRB by the production of sulfides (toxic ions) is responsible for serious health damages (Fuller and Suruda 2000; Lewis et al. 2005) and environmental hazards as metals corrosion, pipeline corrosion in petroleum industries, acidification of oil deposits, and concrete and piping corrosion (Vance and Thrasher 2005).

Bacteriostatic or bactericidal compounds are used to reduce SRB damage to humans and the environment. Thus, metronidazole, oligofructose (Lewis et al. 2005), aldehydes, organosulphur compounds, anthraquinones (Limin et al. 1998), molybdate, chromium (Dianou and Traoré 1996), MgO_2 and/or CaO_2 (Saleh et al. 1964; Lovley and Klug 1983; Zhang et al. 2008), perchlorate (Engelbrektson et al. 2014), and silica (Pati et al. 2016; Barry et al. 2019; Becker et al. 2020) are generally used. In hydroponic cultures, these compounds seem to be beneficial for the growth of rice plants (Dianou and Traoré 1996). However, the accessibility and cost make these chemical compounds difficult to apply in real conditions in rice fields.

7.5.2 Biological Methods to Reduce SRB and IRB Impact in Rice Fields

Cyanobacteria are used as a biofertilizer to promote the growth and yield of several plants as tomatoes and corn. Moreover, Jacq and Roger (1977) reduced the yield losses due to sulfate reduction by inoculating the rice seeds with cyanobacteria. Indeed, cyanobacteria application, during the germination stage of rice, can produce chemical compounds (auxins, vitamins, amino acids, etc.) which accelerate the germination of rice seeds and promote the rice plants' growth (Jacq and Prade 1984; Rodriguez et al. 2006). The growth of cyanobacteria induces soil oxygenation, which decreases or delays the accumulation of toxins ions as sulfides (Jacq and Roger 1977) and ferrous ions. Creating favorable conditions for methanogenic bacteria growth is also a biological alternative to reduce SRB deleterious effect in certain ecosystems; those bacteria compete with SRB for the use of common substrates (Dianou and Traoré 2004; Roger et al. 1999).

7.5.3 Selection of Tolerant and/or Resistant Rice Varieties

The varietal selection remains essential to optimize rice yields. This method consists of a selection of rice varieties that have excellent impermeability to ferrous ions and sulfides and could resist excess salt, water deficits, and parasites (Jacq 1989; Engel et al. 2012). Some rice plants have developed several mechanisms of resistance and/or tolerance to high levels of toxic ions in the soil and/or plant (Becker and Asch 2005; Aung and Masuda 2020). To survive, the rice plants can develop three main adaptation strategies.

The first is the exclusion strategy, in which some rice plants can release oxygen through the root aerenchyma, allowing the formation of an oxidative barrier to prevent the uptake of ferrous ions (Weiss et al. 2005; Engel et al. 2012; Aung and Masuda 2020).

The inclusion strategy is the second method to resist iron toxicity. Iron (II) can be immobilized in less active photosynthetic tissues of stems, leaf sheaths, and phytoferritin (Briat et al. 2010). This mechanism promotes positive regulation of apoplastic pH (Kosegarten et al. 2004; Engel et al. 2012) and reduces iron stress.

The last method commonly used is the inclusion and/or tolerance strategy. The plant can resist high Fe^{2+} content in the leaves, using antioxidant enzymes (superoxide dismutase, catalase, and peroxidase isoenzymes) and non-enzymatic substances (ascorbate and glutathione) that are capable of eliminating free radicals (Majerus et al. 2007).

7.5.4 Application of Fertilization to Reduce Iron and Sulfide Toxicities in Rice Fields

Iron toxicity in rice is a multiple nutritional imbalance caused by Fe^{2+} accumulation in the plant, deficiency of essential minerals (P, K, and Zn), and high soil sulfide content (Fageria et al. 2008; Engel et al. 2012). Indeed, soil high contents in iron (II) and sulfides can be responsible for nutritional imbalances in the plant, by preventing the root absorption of minerals (P, K, Zn, Mg, Ca) essential to plant growth (Fageria et al. 2008; Sahrawat 2010).

Studies showed that the application of adequate fertilizers could significantly reduce the deleterious effects of iron and sulfide toxicities, according to soil type, season, and rice variety (Ethan and Odunze 2011; Ito et al. 2002; Jacq et al. 1991; Sahrawat 2003).

Shu and Chung (2006) also showed that the absorption of minerals (N, P, K) promotes plant photosynthesis, stimulating rice productivity. Moreover, the application of essential minerals such as calcium, magnesium, and zinc, can lead to fighting iron and sulfide toxicities in the plant, by competing with ferrous iron and sulfides on the root sites of absorption, stimulating the defense and tolerance mechanisms of the rice plant (Fageria et al. 2008; Sahrawat 2010). Indeed, Trolldenier (1977) and Prade et al. (1993) showed that potassium and phosphorus application can reduce the soil ferrous iron content by maintaining the oxidative power of the rice root and reducing the absorption of iron II by the rice plant (Jorgensen 1982; Fernández et al. 2010).

To fight iron and sulfide toxicities, farmers can also use the empirical method of organic fertilizers application such as ash and compost (Prade et al. 1993). This process increases soil pH and reduces ferrous ion production in rice fields. The application of silica also aerates the soil and promotes the uptake of mineral compounds essential for rice plant growth (Pati et al. 2016).

7.5.5 *Water Management Methods Used to Control Iron and Sulfide Toxicities*

Few days after the rice paddy soil's submersion, the oxygen in the soil compartments is greatly reduced. The oxygen is consumed during chemical oxidation reactions and biochemical reactions induced by aerobic bacteria (Ponnamperuma 1981). Thus, the stagnation of water in the field leads to a decrease of oxygen in the soil (ADRAO 2002). In the context of continuous lowland submersion, the soil reoxygenation by rice fields water continuous drainage would prevent the accumulation of ferrous and sulfide ions in the rice plant rhizospheric zone (ADRAO 2006; Ethan and Odunze 2011; Keïta 2015).

Providing a sufficient quantity of water to moisten the soil without submersion, could prevent anaerobiosis in the upper part of the soil, and reduce toxic ions production. This method of irrigation must be maintained at the beginning of the rice cultural cycle; as long as the seedling has not developed the air channels that allow it to oxygenate the rhizosphere and protect itself against the damaging effect of ferrous and sulfide ions resulting from the sulfate and iron reduction.

7.5.6 *Cultural Practices to Reduce Iron and Sulfide Toxicities in Rice Fields*

In West Africa, farmers leave the soil bare after the rice harvest in most of the lands in the flat areas. Thus, before sowing, bare and dry soils are exposed to erosion at the beginning of the rainy season (ADRAO 2002). However, the leguminous plants cultivation in the highlands permit to increase the diversity of the rice-based cropping systems, improve soil fertility, and reduce soil erosion and weed pressure (ADRAO 2002). The cultivation of ridges in iron-toxic sites can improve rice yields, as the rice roots end up in an aerobic environment above the waterlogged level (ADRAO 2002). These methods can also help to solve the problem of iron toxicity by preventing leaching along the slopes from the first rains.

7.6 Combined Application of Subsurface Drainage, Fertilization, and Rice Varieties to Reduce Iron and Sulfide Toxicities in Rice Fields

The onset of iron toxicity symptoms in rice requires excessive Fe^{2+} and H_2S^- roots uptake and accumulation in the leaves (Becker and Asch 2005). The production of the toxic ions is strongly linked to the metabolism of IRB and SRB present in rice paddy soils.

Many studies showed that fertilization (Ethan and Odunze 2011; Taylor and Fageria 2014), adequate soil drainage (Kosaki and Juo 1986; Audebert and Sahrawat 2000), and varietal selection (Onaga et al. 2013) had an impact on the emergence of iron and sulfide toxicities in the affected rice fields. However, the constraint remains because the research was conducted separately and does not involve the microorganisms responsible for the phenomenon. To remedy this deficiency, research was carried out in Burkina Faso to evaluate the impact of the combined application of fertilization, subsurface drainage and rice varieties on the occurrence of iron and sulfide toxicity symptoms.

Several studies were conducted in pots and microplots. During the research, four frequencies of subsurface drainage (D0: undrained, D1: drained for 7 days, D2: drained for 14 days, and D3: drained for 21 days) were tested, as reported by Otoidobiga et al. (2015a). Moreover, to optimize rice production, three rice varieties, namely, popularized, sensitive, and tolerant to iron toxicity (FKR19, BOUAKE189, and ROK5), and five levels of fertilization (NF: unfertilized, Silica, NPK + Urea, NPK + Urea + Ca + Mg + Zn, and NPK + Urea + compost) were applied according to Otoidobiga et al. (2016a, b). The silicate was applied at the dose of 120 g/m^2 and the compost at the dose of 4 T/ha. The undrained and unfertilized (D0/NF) pots were used as controls. The experiments were performed in dry and rainy seasons. IRB and SRB population dynamics, iron II and sulfide contents, were monitored in the plant rhizosphere during the crop cycle by most probable number (MPN) and colorimetric methods, as indicated by Otoidobiga et al. (2015a, b). The rice plant iron content was also determined by colorimetry method (Otoidobiga et al. 2016b).

The study demonstrated the presence of IRB (Otoidobiga et al. 2015a, b, 2016a) on the nontoxic soil of Kamboinsé and on the iron toxic sites of the Kou Valley, Tiefora and Moussodougou. These results confirm the hypothesis that any type of soil could be affected by the iron and sulfide toxicities (Hammann and Ottow 1974). Indeed, IRB and SRB are ubiquitous bacteria found on all types of soil (Hammann and Ottow 1974).

Furthermore, the experiments showed that the number and activity of IRB and SRB populations increased in the soil a few days after submersion (Otoidobiga et al. 2015a, b). Reduction processes begin after soil flooding, when the redox potential of the medium drops below 180–150 mV, (Patrick and Reddy 1978; Conrad 2007; Hori et al. 2010). With the depletion of oxygen, mineral compounds (NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}) are used as electron acceptors by microbes during the respiration process (Liesack et al. 2000).

The ability of some IRB and SRB to sporulate may also justify these results. Thus, these bacteria can survive in alternating anaerobic and aerobic conditions of paddy fields soil, during the dry and rainy periods and during the periodic seasonal submersion and drainage (Widdel 1992; Stubner and Meuser 2000). Under the reducing conditions of submerged rice fields, the bacteria present in the soil are activated and set up anaerobic respiration. Ferric and sulfate ions (Fe^{3+} and SO_4^{2-}) are reduced, releasing large amounts of ferrous and sulfide ions into the soil solution. Thus, soil submersion is the main factor, stimulating the proliferation and activity of the IRB and SRB populations in rice paddy soils (Otoidobiga et al. 2015a, b).

IRB and SRB population dynamics and activities recorded during the rice growth cycle revealed peaks during tillering, flowering, and maturation periods, despite treatments (subsurface drainage and/or fertilization) applied (Otoidobiga et al. 2015a, b, 2016a, b). Jacq et al. (1991) and Dianou and Traoré (2000) showed a similar evolution of the number and the activity of IRB and SRB, respectively in the rice paddy soils of Senegal and Burkina Faso. The peaks observed during the growth cycle of rice are related to the abundance of organic substrates released into the rhizosphere at these stages of growth (Jacq 1975; Loyer et al. 1982).

Jacq (1980) and Yi et al. (2012) showed also that the maturation and tillering stages correspond respectively to the most reduced states of the rice field soils and to a change of the nature and importance of the root exudates, which induces proliferation of IRB and SRB populations in the rhizosphere. Thus, the physiological condition of rice plants is one of the major factors inducing iron and sulfide toxicity in the field (Otoidobiga et al. 2016b).

Many studies showed that the dynamics of IRB and SRB populations in rice paddy soils are not correlated with their activity (Jacq et al. 1991; Dianou and Traoré 2000). Indeed, ferrous ions and sulfides abiotic oxidation (Jacq et al. 1991), ferric iron and sulfate abiotic reduction processes can influence the toxic ions content in affected soils. Some bacteria are able to oxidize Fe (II) and sulfides under aerobic and anaerobic conditions, affecting the soil ions content (Straub et al. 1996; Liesack et al. 2000; Erbs and Spain 2002).

The study conducted revealed the survival of IRB and SRB in the soil despite the subsurface drainage application, confirming the hypothesis that some of these bacteria can grow in flooded soil with low oxygen pressure (Erbs and Spain 2002; Ebrahiminezhad et al. 2017).

The research also showed that the combination of subsurface drainage and fertilization methods significantly reduced the number and activity of IRB and SRB populations in paddy soils for all rice varieties (susceptible and resistant) tested (Otoidobiga et al. 2016a, b).

Oxygenation of the soil via drainage oxidizes ferrous iron and sulfides inducing the oxidation of Iron II and sulfides produced into ferric iron and sulfate, nontoxic for rice plants (Liesack et al. 2000; Ethan and Odunze 2011). Moreover, the application of mineral fertilizers (N, P, K) stimulates the ability of rice roots to oxidize ferrous iron and sulfides, resulting in the precipitation of ferric iron and sulfate on the root surface (Trolldenier 1977).

The analysis evidenced that the jointed application of the subsurface drainage and fertilization increased the total iron content of roots and leaves (Otoidobiga et al. 2016a, b) and the yields (Figs. 7.2 and 7.3). Thus, the simultaneous application of subsoil drainage and fertilization (D2 + NPK + Urea + Ca + Zn + Mg, compost) appears to have a beneficial and synergistic effect on optimal iron uptake by the rice plant and effective yield improvement (Otoidobiga et al. 2016b).

Therefore, subsurface drainage would transform toxic Fe^{2+} to Fe^{3+} (nontoxic), and fertilizers (NPK + Urea + Ca + Zn + Mg, compost) would contribute to optimal iron acquisition and increase the tolerance of rice plants to iron ions (Fageria et al. 2008; Ethan and Odunze 2011; Otoidobiga et al. 2016b).

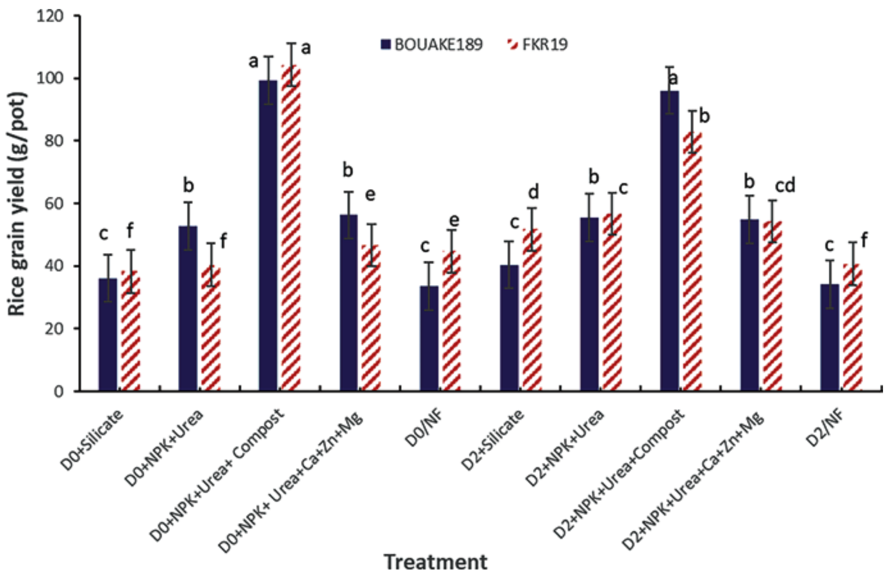

Fig. 7.2 Grain yield of rice varieties BOUAKE189 and FKR19. D0: undrained, NF: unfertilized, D2:drained for 14 days, fertilization mode: Silica, NPK + Urea, NPK + Urea + Ca + Zn + Mg, NPK + Urea + compost, (mean of 3 replications). Yields with a letter in common are not significantly different based on Fisher's test $p > 5\%$

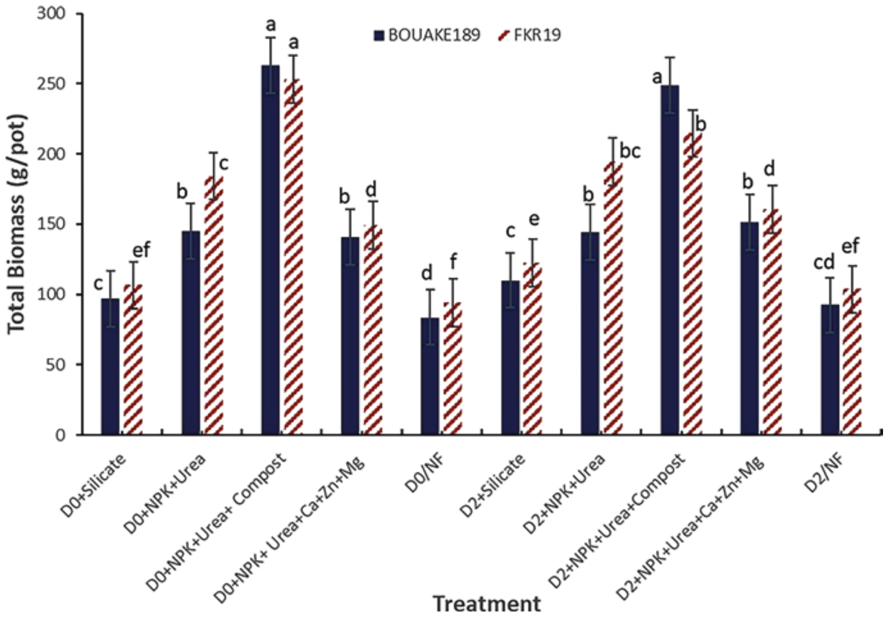

Fig. 7.3 Yield of the total biomass of BOUAKE189 and FKR19 rice varieties. D0: undrained, NF: unfertilized, D2:drained for 14 days, fertilization mode: Silica, NPK + Urea, NPK + Urea + Ca + Zn + Mg, NPK + Urea + compost, (mean of 3 replications). Yields with a letter in common are not significantly different based on Fisher's test $p > 5\%$

Studies revealed that Ca, Zn, and Mg ions compete with sulfides and ferrous ions at the uptake sites of rice plant roots and induce resistance to high levels of toxic ions (Fageria et al. 2008; Sahrawat 2010; Otoidobiga et al. 2016b).

In summary, the simultaneous application of subsoil drainage and fertilization reduces the impact of IRB and SRB activities on the productivity of sensitive and tolerant rice varieties in both the wet and dry seasons. These treatments also allowed to optimize the rice plant growth and increase productivity. To improve the productivity of rice in iron and sulfide toxicities conditions, the following treatment should be applied for all rice varieties (sensitive or tolerant):

- A continuous and regular subsurface drainage for 14 days
- NPK (200 kg/ha), zinc (10 kg/ha), calcium (250 kg/ha), and magnesium (8.92 kg/ha) fertilizers to be applied the day of transplantation,
- Application of urea in two fractions (35 kg/ha and 65 kg/ha) respectively on the day of transplanting and 60 days after the transplantation,
- Compost, which is more accessible and less expensive for farmers, can be used as a replacement for the Ca + Zn + Mg fertilizer complex, at the dose of 4 T/ha before transplanting.

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Chapter 8
Is Food Medicine? Lessons From a Household Survey on Plants Used to Manage Anaemia in Kilifi County, Kenya

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8.1 Introduction

The debate as to whether food is medicine or food can be medicine depends on the context and the desired effects upon the use of food to alleviate diseases that occur and reoccur in communities. In most cases, medicinal foods are thought to prevent, manage or/and treat rampant illness in any particular community. In a typical example, medicinal herbs found in rural communities of West Africa have been used effectively to treat sickle cell, which in itself provides indications that several bioactive constituents in natural products have the ability to protect or cure ailments (Adejumo et al. 2012). In addition, most plant species have been noted to avert problems of food shortage thereby enhancing nutritional requirements in fragile ecosystems (Nahonyo et al. 2002). While it is possible that 80% of people in many developing countries use medicinal plants to fulfil primary health needs (WHO 2002), the perception by the public about herbal plant medicines being safe and natural does not exempt them from being potentially toxic to humans. It is for this reason that studies to substantiate and evaluate potential clinical efficacy, possible side effects and toxicity in preparations and compounds are imperative.

To be a source of food, the medicinal plants/herbs need to be rich in vitamins, fats, proteins, carbohydrates and minerals. The food could also contain ingredients that aid specific body functions and improve our health and well-being (El Sohaimy 2012). Foods that bridge a gap between provisions of nutrients such as iron and serve as medicine at the same time are referred to as nutraceuticals (Pandey et al.

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2010). From this perspective, there is need to understand the health benefits of plant species that are regarded to have superior capabilities with ability to treat, manage and even control nutritional disorders. Medicinal plant species can be regarded as functional foods when positive results are attained with successful elimination of nutritional disorders such as anaemia. A guarantee on safety on consumption of the "super foods" establishes a new opportunity to improve health, reduce health care costs and support economic development in rural communities (El Sohaimy 2012).

Rural communities in malaria endemic zones such as Kilifi County in Kenya rely on phytomedicines as food as well as medicine to control anaemia and other illnesses that occur alongside anaemia such as malaria. The reasons why local populations consume functional foods range widely and include compensating for a perceived or potential inadequacy in the diet; a scenario synonymous within population groups who generally assume basic dietary adequacy may not always be secure (Webb 2006). Another reason is to compensate for increased need of a certain nutrient or when a body system is defective in the handling of a nutrient. Examples of such instances include, blood losses, for example, due to parasite infestation, heavy menstruation or repeated pregnancies (Webb 2006). In other cases, phytomedicines are taken to treat or prevent non-deficiency diseases such as malaria that could be recurrent. In such cases, the intake of functional foods propagates quick recovery and could indirectly control the occurrence of anaemia.

In this chapter, we report the findings of a cross-sectional household survey that assessed medicinal plants used in treatment, control and management of anaemia in Kilifi County of Kenya. The investigation is crucial, as it will provide an insight as to whether the medicinal plants could be utilized in optimizing anaemia treatments in future. Similar investigations on Yoruba herbal medicine in Nigeria, led to eventual development of NIPRISAN, a drug for sickle-cell anaemia treatment. NIPRISAN (Nix-0699), currently going by the trade name Nicosan, is a product of four different plants, (*Piper guineenses* seeds, *Pterocapus osum* stem, *Eugenia caryophyllum* fruit and *Sorghum bicolor* leaves). Nicosan anti-sickling properties significantly reduced the number of painful episodes in patients with sickle cell anaemia (Iyamu et al. 2002; Okpuzor et al. 2008).

8.2 Methodology

8.2.1 Study Area

The household survey was conducted in the former Kilifi District of Kilifi County in Kenya in October 2012/2013 (Fig. 8.1). Though administratively subdivided, the Kenya Ministry of Health regarded the former Kilifi district (now Kilifi County) as one unit. The county is located on the South East of Kenya, lies next to the massive water body of the Indian Ocean at the Kenyan coast, and has Kilifi town as its administrative centre. The region is considered an Arid and Semi-Arid Land (ASAL) mainly relying on dry land arable farming, formal and informal employment as

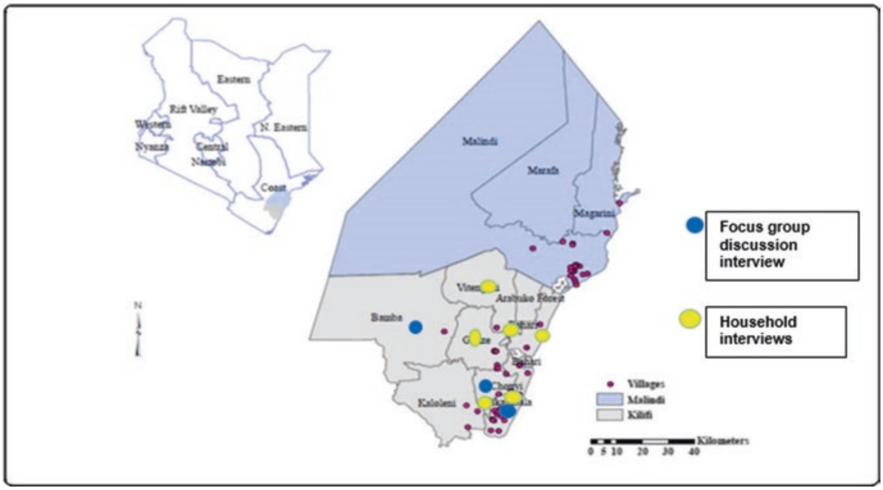

Fig. 8.1 The map of Kilifi County and sites of the cross-sectional household survey and focus group discussion. (Note that during the time of the study Kaloleni was not considered part of Kilifi County. Source: Mwangangi et al. Malaria Journal 2013, 12:13)

major economic activities. Tourism is also a key income-generating activity in the region. In terms of population, the County boasts of 528,397 persons (Kilifi County Strategic Plan 2005–2010; Central Statistics Office 2007). The residents of Kilifi County, who are mainly from the Mijikenda ethnic group, prefer traditional medicine as a primary form of health care (Kilifi County Strategic Plan 2005–2010).

8.2.2 Household Survey and Data Collection

The household survey included 541 households identified randomly and was conducted in the year 2012/2013 after obtaining ethical board approval and a research permit from relevant authorities. The objectives of the study were clearly stated to the respondents and their participation was strictly on a voluntary basis. A semi-structured questionnaire was used in data collection. Sections of the questionnaire included enquiries of whether members in the household had suffered from anaemia in the past and whether that person had used medicinal/food plant to manage anaemia. Another section probed the particulars of the plants that had been used in the management of anaemia. In particular, the section asked for the name of the plant, the respective plant part, the mode of preparation, and the mode of application. Furthermore, the duration of treatment, as well as the healing period and the completeness of recovery were established. Finally, a section asked about the availability of the respective plant in the community. The interviews were conducted in Swahili and Mijikenda languages with the help of a research assistant who had grown up in the area and knew the local language (Mijikenda) well, and responses were recorded in English, with the aid of local translators. The research team to test the appropriateness of the research tools first conducted a pilot study, and any necessary revisions were incorporated.

The survey was complemented by two different sets of FGDs that were held in Kilifi County in October 2012. The first set of the FGDs involved various groups in Kikambala and Bamba discussions with 88 participants drawn from different backgrounds, and a second set involved a report-back workshop with 66 participants carried out at Kolongoni. The focus group discussion complemented exploratory stages of the cross-sectional household baseline study, in a bid to evaluate and validate findings on anaemia occurrence in Kilifi County. In essence, the report-back workshop was geared to collect feedback from the THPs, community members/village elders and the community health officers.

The first set of FGDs had 12 focus group discussions (FGD) of 6–13 participants (total of 88 participants), 7 of which were held in Kikambala Division and 5 took place in Bamba Division. The participants in focus group discussions shared diversity in characteristics, such as age, gender, ethnicity, social standing and occupation (Vaughn et al. 1996; Morgan and Krueger 1993; Morgan 1988). These social differences complemented each other and enabled participants to discuss and crosscheck each other's viewpoints. The second set of FGDs consisted of a feedback workshop that was held in Kolongoni Primary school that sought to validate results obtained from the cross-sectional household survey.

The purpose of the focus group discussion was to capture generalized, rather than specialized, knowledge shared at community level (Vaughn et al. 1996; Morgan and Krueger 1993; Fettermman 1989; Morgan 1988). Specifically developed FGD guides included questions on occurrence of anaemia in the household, local medicinal/food plant used in anaemia management including the part of the plant used, mode of preparation and recovery period. Qualitative data from FGD were thematically analyzed.

8.2.3 Selection of Plant Species for Quantification of Iron Content

The iron and vitamin C content of the top ten plants mentioned with highest frequencies by households were established using atomic absorption spectrophotometry (Association of Official Analytical Chemists-AOAC 1996).

8.2.3.1 Preparation of Plant Samples to Determine the Mineral Content

Three (3) g of each plant sample was weighed and subjected to drying in a porcelain crucible at 450 °C in a muffle furnace for 24 hours. Ashes were allowed to cool at room temperature. The ashes (0.3 g) were dissolved in 5 ml of concentrated hydrochloric acid in order to precipitate all the particles towards the bottom of the crucible. The final volume was adjusted to 50 ml with distilled water. The solution was filtered twice with filter paper and the filtrate collected for more analysis.

8.2.3.2 Determination of Iron Content in the Plant Samples

The total iron content in the standard solution and samples of selected plants was obtained using atomic absorption spectrophotometer (Association of Official Analytical Chemists-AOAC 1996). The iron concentration of each sample was calculated graphically using a calibration curve in the linear range by plotting the extract concentration vs. the corresponding iron content. Then, the content of iron of each sample was calculated using the following formula:

$$\text{Iron content}\left(\frac{\text{mg}}{100\text{g}}\right) = \left(C^{*}\text{DF}^{*}100\right)/P\ \text{Iron content}\left(\text{mg}/100\text{g}\right)$$
$$= \left(C \times \text{DF} \times 10 \times \%\right)/P\ \text{Iron content}\left(\text{mg}/100\text{g}\right)$$
$$= \left(C \times \text{DF} \times 10 \times \%\right)/P$$

where C is the iron concentration of the sample, obtained from the calibration curve (mg/g)

DF: Dilution Factor, P: Mass of ash (g).

8.2.3.3 Determination of Vitamin C Content

The ascorbic acid content of fruits and vegetables was determined by macerating the sample mechanically with a stabilizing agent of 5% metaphosphoric acid or trichloracetic acid and titrating the decanted or filtered extract with 2,6 dichlorophenolindophenol. The method proposed by Loeffler and Ponting (1942) was modified to measure vitamin C using absorptiometer. The absorptiometer was adjusted to zero, using distilled water and a green filter at 520 nm. To tube No.1, 9 ml of standard dye solution (0.0012%) was added and mixed. The readings were recorded after exactly 15 seconds, and labelled as *L1*. The instrument was then adjusted to zero with tube S (a blank that contained distilled water) in the absorptiometer. To tube 2, 9 ml of dye was added, mixed and read after 15 seconds (*L2*). Recordings for *L1* and *L2* for each working standard and construction of standard curve with concentration of ascorbic acid (mg/100 ml) as abscissae was done, after which the difference between *L1*and *L2* for each working standards as ordinates was calculated.

Five grams of the plant sample was macerated for 3 minutes with a mortar and pestle with 35 ml of 0.4% oxalic acid solution and filtered. *L1* was obtained as described, while to tube S, 1 ml of filtrate and 9 ml water were added and used to adjust the instrument to zero. Then to tube No.2, 1 ml filtrate and 9 ml dye were added and recorded as *L2* after 15 seconds. The difference between L1 and L2 was determined and the concentration of ascorbic acid obtained from the standard curve. Assays were performed in triplicates.

8.2.4 Data Analysis

Quantifiable data from the household questionnaire was entered into Microsoft Excel data templates and crosschecked for consistency and accuracy. The data was then descriptively analyzed for frequency distributions and cross tabulations using Statistics Package for Social Scientists Version 17 (SPSS, Atlanta, USA). Qualitative data from open-ended questions, from focus-group discussions were coded according to themes, which provided the basis for analysis (Miles and Huberman 1994). Relative frequencies and percentages of variables were graphically compiled using Excel software.

8.2.5 Ethical Considerations

The research ethical review board of Kenyatta National Hospital/University of Nairobi approved the study (Ref: KNH-ERC/A/170). Informed consent was obtained from participants with respondents being assured of anonymity at all stages of data collection and analysis.

8.3 Results

8.3.1 Occurrence of Anaemia in the Household

The occurrence of anaemia within the household provided information about how many households ($N = 541$) had suffered from anaemia and formed the basis on which recommendations would be made on anti-anaemia plants (Table 8.1).

In addition, the demographic information provided the most at-risk household member(s) likely to suffer from anaemia in the household. A large majority of households (92.8%) indicated that they have experienced an episode of anaemia in the past (Table 8.1). Close to half, (49.8%) of anaemia sufferers were expectant females in the household, followed by children under the age of 5 years in 26.4% of households and non-expectant females in 16% of sampled households. It was observed that children between 5 and 13 years (5.7%), children below the age of 1 year (3.6%) and male members (2%) of households had experienced anaemia to a lesser extent.

Most households (95.7%) reported to have used herbal medicine in treatment of anaemia. A majority (78.1%) of the households reported that when they used herbs, they obtained complete recovery (self-reported recovery) from anaemia, although

Table 8.1 Occurrence of anaemia in households and any medicinal/food plant used in anaemia management in Kilifi ($n = 541$)

Variable		*N* (%)
Household with experienced episodes of anaemia	Yes	502 (92.8)
	No	39 (7.2)
Household member who suffered from anaemia	Children <1 year	18(3.6)
	Children <5 years	116(22.9)
	Children 5–13 years	29(5.7)
	Expectant women	252(49.8)
	Non-expectant women	81(16)
	Male	10(2)
Frequency of anaemia episodes	Once	365 (73)
	Repeatedly	135 (27)
Use of herbal medicine	Yes	512(95.7)
	No	23(4.3)
Recovery after herbal treatment	Treatment was complete	403(78.1)
	Repeated treatment was required	113(21.9)

21.9% reported that they had required a repeat of the treatment. Given that most community members (95.7%) resorted to using natural herbal medicine in treatment of anaemia, the study sought to establish the most frequently mentioned plant species used for anaemia management in the community mainly because decisions made by households to seek treatment when faced with a situation of ill health of a household member are partly influenced by sociocultural beliefs about the curability of the disease.

8.3.2 Frequently Used Plant Species for the Management of Anaemia

Given the apparent preference of households to use nutri/medicinal plants, household members were asked to mention the most frequently used plants in treatment of anaemia, the parts of the plants that were used, the mode of preparation and the effective dose. From the household interviews ($N = 541$), it emerged that most of the frequently mentioned plants were common edible fruits or vegetables (Table 8.2). They were mostly boiled and consumed on a plate, or the soup was decanted and consumed in a cup (Fig. 8.2).

Since in the study we wanted to determine the most effective nutri/medicinal plant, a cutoff point of 15 households was used in establishing frequency of the nutri/medicinal plants (Table 8.2). Some of the most frequently mentioned plants included the following: first the *Morus alba* L. (127/541), locally referred to as *Mribena.* The most used part of the *Morus alba* L. is the fruit. The fruits are boiled and the resultant juice is consumed for added health benefits that include blood building. *Amaranthus hybridus* L. (163/541) is the second most frequently

Table 8.2 Most commonly used plants by households in Kilifi to manage anaemia

Species/ voucher specimen no.	Plant Family	Local name	Frequency of mention	Plant part used	Mode of preparation	Dose/ day	Supporting Literature anaemia	Supporting Literature malaria
Morus alba L. (NM2014/44)	Moraceae	Mribena	197	Fruits	Boiled	3 cups	In direct anti-anaemic activity include: - antioxidant /anti-helmintic/antimicrobial (Mnaa et al. 2015; Huang et al. 2013; Naik et al. 2015; Bondada et al. 2014; Devi et al. 2013; Kaewkaen et al. 2012; Wattanathorn et al. 2012).	Malaria-related symptoms (Singh et al. 2013)
Amaranthus hybridus L. (NM2014/17)	Amaranthaceae	Mchicha	163	Leaves	Boiled	1 plate	Nutrient rich, Achigan-Dako et al. 2014; minimal haematinic activity (Ogbe et al. 2010).	Malaria-related symptoms (Achigan-Dako et al. 2014).
Moringa oleifera Lam. (NM2014/18)	Moringaceae	Mzungi	65	Leaves	Boiled	1 plate	Increases haematology indices (Moyo et al. 2011; Babu 2000). Anti-sickling activity (Adejumo et al. 2012).	Anti-pyretic (Singh and Kumar 1999)
Vigna unguiculata (L.) Walp. (NM2014/05)	Papilionaceae	Mkunde	60	Leaves	Boiled	1 cup	None	None
Launaea cornuta (Hochst. ex Oliv.& Hiern) C. Jeffrey (NM2014/20)	Compositae	Mchunga	57	Leaves	Boiled	2 cups	No effect on haematological parameters (Muriira 2014).	Traditionally used as anti-malarial (Nahonyo et al. 2002)
Zanthoxylum chalybeum Engl. (NM2014/15)	Rutaceae	Mndungu	52	Roots/ Bark	Boiled	2 cups	None	Anti-plasmodial activity (Nguta et al. 2010a, b; Patiño et al. 2012; Bbosa et al. 2014)

Species/ voucher specimen no.	Plant Family	Local name	Frequency of mention	Plant part used	Mode of preparation	Dose/ day	Supporting Literature anaemia	Supporting Literature malaria
Vernonia microcephala DC. (NM2014/47)	Compositae	Muboho	30	Roots	Boiled	3 cups	None	None
Grewia densa K. Schum (NM2014/34)	Tiliaceae	Mkone	20	Fruits	Boiled	1 cup	None	None
Lannea schweinfurthii Engl. (NM2014/29)	Anacardiaceae	Mnyumbu/ Mchumbu	20	Leaves	Boiled	3 cups	None	None
Kigelia africana (*Lam.*) Benth. (NM2014/45)	Bignoniaceae	Mnyahi	18	Roots	Boiled	1 cup	Traditional control of *post–partum hemorrhage* (Gill 1992)	*Anti-malarial* (Binutu et al. 1996; Weiss et al. 2000 and Saini et al. 2009)
Cassia occidentalis L. (NM2014/03)	Caesalpinaceae	Mtsalafu	15	Whole plant	Boiled		In direct anti-anaemic activity include - antioxidant (Yadav et al. 2004 /anti-helminthic (Kateregga et al. 2014), antimicrobial (Sadiq et al. 2012, Manikandaselvi et al. 2016)	Anti-malarial (Tona et al. 2001; analgesic and anti-pyretic (Saini et al. 2009)

Fig. 8.2 Workshop held at Kolongoni Division, Chonyi County

mentioned effective nutri/medicinal plant also commonly known as *Mchicha* in Kilifi County. Others were *Moringa oleifera* Lam. (65/541), *Vigna unguiculata* (L.) Walp. (60/541), *Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey (60/541) and *Zanthoxylum chalybeum* Engl. (57/541). The least frequently mentioned but apparently the most effective nutri-medicinal plant was *Kigelia africana* (*Lam.)* Benth. and *Cassia occidentalis* L. (15/541) locally referred to as *Mnyahi* and *msta-alafu* respectively in *Kiswahili*.

8.3.3 Perceived Efficacy, Health Outcome and Respective Iron and Vitamin C Content

The nutri/medicinal plants mentioned were evaluated for their apparent effectiveness in reference to anaemia management as highlighted in Table 8.3. Other than the apparent efficacy, in vitro analysis was performed to determine the iron and vitamin C content of the plant. Whereas iron is an important part of the haemoglobin molecule, vitamin C is crucial in enhancing the bioavailability of non-heme iron from plants as well as mobilization of iron within the body.

The results showed that *Morus alba* L. was considered the most effective nutri/medicinal plant by 150/541(27.7%) of the households in Kilifi County. *Amaranthus* *hybridus* L. was mentioned in 102/541 (18.9%) households as the plant giving the most effective treatment. Other plants were mentioned less than 20 times. These included *Moringa oleifera* Lam., *Vigna unguiculata* (L.) Walp., *Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey, *Zanthoxylum chalybeum* Engl., *Vernonia microcephala* DC., *Grewia densa* K. schum, *Lannea schweinfurthii* Engl., *Kigelia africana* (*Lam.)* Benth. and *Cassia occidentalis* L. The most consumed part of the plant was the leaves. Rarely were roots, barks or whole plant considered for treatment. In most cases, proposed healing period was between 1 and 2 weeks, although in other cases for example where *Lannea schweinfurthii* Engl. and *Zanthoxylum chalybeum* Engl. were used, treatment was mentioned to be less than a week. The treatment schedules were observed to be shorter than those from the guidelines provided at the County health services clinic with the prescription of 600 mg/day ferrous sulphate (12 mg/day elemental iron) for 3 months given in divided doses (1 to 3 times daily), for adults, and 15 to 30 mg/kg bw/day ferrous sulphate (3 to 6 mg/kg/day elemental iron) in paediatric treatment of 0–5-year-old children (Maakaron et al. 2021). In all cases of nutri/medicinal use, total recovery was reported although repeated treatment was considered necessary in a few cases.

Iron and vitamin C content of all the frequently mentioned nutri/medicinal plants in Kilifi County were analyzed (Table 8.3). *Morus alba* L. had the highest iron content (25 mg/100 g) among the nutri/medicinal plants mentioned and had a vitamin C content of 15 mg/100 g which may translate to less iron bioavailability in the plant source considering the role of vitamin C in enhancing the bioavailability of non-heme iron from plants as well as mobilization of iron in the body (Fishman et al. 2000).

The second most mentioned plant was *Amaranthus hybridus* L. leaves which had iron and vitamin C content of 13 mg/100 g 2.41 mg/100 g respectively. *Moringa oleifera* Lam. leaves were found to have high deposits of iron (20 mg/100 g) and vitamin C (48 mg/100 g) suggestive of a potentially effective anti-anaemic plant. According to the residents of Kilifi, after the proposed 1–2 weeks of administration of the nutri/medicinal dosage, the treatment was considered complete, and treatment was rarely repeated (Table 8.3).

It was observed that at times the treatment using Moringa leaves was combined with its green pods. *Morus alba* L. and *Amaranthus hybridus* L. leaves, *Grewia densa* K. schum leaves were found to be rich in vitamin C (20.76 mg/100 g), whereas for *Kigelia africana* (*Lam.)* Benth., the roots were among those found to be rich in vitamin C (27.87 mg/100 g); an amount that is almost equivalent to that found in tangerines.

The *Morus alba* L. had a non-heme iron of 25 mg/100 mg and vitamin C content of 15.2 mg/100 g, *Cassia occidentalis* L. was observed to have iron content of 14.3 mg/100 g and the highest vitamin C content of 50.25 mg/100 g comparable to that of pepper (50.04 mg/100 g) as measured in the laboratory. Even though *Cassia*

Table 8.3 Perceived efficacy, health outcome and iron and vitamin C content

Species/ voucher specimen no.	Plant part	Frequency of being ranked as most effective	Proposed healing period	Proposed complete recovery	Repeated treatment required	Fe content (mg/100 g)	Vitamin C (mg/100 g)
Morus alba L. (NM2014/44)	Fruits	150	1–2 weeks	Yes	Rarely	**25.1**	15.2
Amaranthus hybridus L. (NM2014/17)	Leaves	102	1–2 weeks	Yes	Sometimes	13.58	2.41
Moringa oleifera Lam. (NM2014/18)	Leaves	23	1–2 weeks	Yes	Rarely	**20**	**48.6**
Vigna unguiculata (L.) Walp. (NM2014/05)	Leaves	24	1–4 weeks	Yes	Rarely	3.3	6.57
Launaea cornuta (Hochst. ex Oliv.& Hiern) C. Jeffrey (NM2014/20)	Leaves	18	3–4 weeks	Yes	Never	13.5	1.67
Zanthoxylum chalybeum Engl. (NM2014/15)	Roots/ Bark	25	<1 week	Yes	Often	4	4
Vernonia microcephala DC. (NM2014/47)	Roots	16	1–2 weeks	Yes	Sometimes	2.3	4.68
Grewia densa K. Schum (NM2014/34)	Leaves	13	1–2 weeks	Yes	Never		**20.76**
Lannea schweinfurthii Engl. (NM2014/29)	Leaves	11	<1 week	Yes	Often	7.6	4.9
Kigelia africana (*Lam.*) Benth. (NM2014/45)	Roots	13	1–2 weeks	Yes	Never		**27.87**
Cassia occidentalis L. (NM2014/03)	Whole plant	08	1 week	Yes	Never	14.3	50.26

occidentalis L. was not the most frequently mentioned plant in the household survey, the information that the treatment duration mentioned was short (1 week) and that recovery was considered complete made the plant to be considered as having a high potential as a haematenic plant in the malaria-endemic region of Kilifi County, and was therefore considered for further phytochemical and prophylactic experiments.

8.3.4 Availability and Sources of the Nutri/Medicinal Plants

Traditional medicine is generally considered highly available and accessible to people in developing countries, and continues to be an integral part of primary healthcare for both the rural and urban populace. The availability of nutri/medicinal plants is, therefore, one factor that is likely to influence patients' health-seeking choices. It was, therefore, deemed necessary to investigate the availability of the mentioned nutri/medicinal plants. The responses from the participants in terms of the availability of these plants are listed in Table 8.4.

Most households (95.7%) mentioned that the plants were readily available with the sources of origin varying from wild (32.2%), to having been deliberately cultivated (54.3%) and to being purchased from various sources (9.5%). Very few households (0.6%) relied on plants that had been imported from other regions or that were from both cultivation and wild sources. It was observed that with the high rates of deforestation in Africa, communities/households seemed to switch to more reliable and sustainable sources (cultivation) in acquiring nutri/medicinal plants.

8.4 Discussion

8.4.1 Frequently Used Plant Species for the Management of Anaemia

Following the cross-sectional household survey, 95% of the households mentioned that they had experienced anaemia in the past. The most affected groups were pregnant women and children below 5 years. Further revelations showed that the

Table 8.4 Availability of medicinal plants mentioned

	Variables	Number (%)
Availability of the functional herbs	Yes	494(95.7)
	No	22(4.3)
Sources of herbs	Collected from wild	166(32.2)
	Cultivated	280(54.3)
	Sold	49(9.5)
	Imported	39(0.6)
	Cultivated and imported	11(2.1)
	Collected from wild and cultivated	7(1.4)

majority of households used herbal medicine for anaemia management with most of the anaemic patients (78%) reporting recovery (self-recovery). These herbs were, thus, investigated. Since many edible herbal plants are perceived to have health benefits (Herforth 2010; Kassam et al. 2010), and play an important role in supplementing diets (Herforth 2010; Shackleton and Shackleton 2004), the biggest task is differentiating between those plants with the ability or potential to treat and correct the ailments and /or disorders from those that do not.

The fruits of *Morus alba* L. were the most frequently mentioned in management of anaemia in Kilifi County. The mode of preparation involved boiling the plant and consuming three cups of the aqueous extracts. Scientific information shows *Morus alba* L. has indirect anti-anaemia properties such as antioxidant, anti-helminthic, antimicrobial (Mnaa et al. 2015; Naik et al. 2015; Huang et al. 2013; Bondada et al. 2014; Devi et al. 2013; Kaewkaen et al. 2012; Wattanathorn et al. 2012) and possibly anti-malarial (Singh et al. 2013). *Amaranthus hybridus* L., which was the second most frequently mentioned nutri/medicinal plant in the area of study, was boiled and served on a plate. This makes it be perceived as a common vegetable. Minimal haematenic activity is observed with the use of *Amaranthus hybridus* L. (Ogbe et al. 2010) even though it is considered a rich source of iron (Achigan-Dako et al. 2014). *Amaranthus hybridus* L. is likely to find application in management of malaria-related symptoms (Achigan-Dako et al. 2014)

Moringa oleifera Lam. is boiled and consumed as a vegetable. It is observed that one plate (approximately 300 ml) of *Moringa oleifera* Lam. is enough serving to provide nutritional benefits that supplement the body with enough nutrients (Table 8.2). *Moringa oleifera* Lam. as a medicinal plant is accessible, available and valuable, especially at times of inadequate access to nutritious food, health care and/or conventional medicine (Muthaura et al. 2007; Kitula 2007). Additional benefits endowed by *Moringa oleifera* Lam. consumption is the anti-sickling activity that emanates from its ability to control sickle cell disease (Adejumo et al. 2012). Other medicinal plants used in management of anaemia include, *Vigna unguiculata* (L.) Walp., *Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey, *Vernonia microcephala* DC, *Grewia densa* K. Schum, *Lannea schweinfurthii* Engl. On the other hand, *Zanthoxylum chalybeum* Engl., *Kigelia africana* (*Lam.)* Benth. and *Cassia occidentalis* L. was found to have anti-malarial activity. Malaria could indirectly influence the occurrence of anaemia if not controlled.

The results obtained in the survey are indicative of the role played by traditional medicine in addressing health needs of a community, particularly in areas where infectious diseases are highly prevalent and conventional health care is likely to be elusive (Johns and Chapman 1995; Kassam et al. 2010). Since malaria is considered to be the principal cause of severe anaemia in malaria-endemic areas of Africa, members of many communities are likely to use medicinal plants such as *Zanthoxylum chalybeum* Engl., *Kigelia africana* (*Lam.)* Benth. and *Cassia occidentalis* L., which have anti-malarial activity for anaemia management. This goes hand in hand with the recent reports whereby anaemic patients are treated for malaria in malaria-endemic areas in Africa (Reyburn 2010).

In other cases, hookworm infection, which has been witnessed to cause anaemia in children under 2 years (Brooker et al. 2006), can be managed with a medicinal plant such as *Morus alba* L. and *Cassia occidentalis* L. that have anti-helmintic properties (Kateregga et al. 2014). All the same, an effective nutri/medicinal plant supplements nutrients and promotes optimum health (Moyo et al. 2011; Babu 2000) mainly because anaemia occurs as a multi-causal disorder, consequently affecting the growth and development of children and reducing the productivity of adults.

8.4.2 Perceived Efficacy, Health Outcome and Respective Role of Iron and Vitamin C Content

Iron, is a vital mineral for proper functioning of haemoglobin; a protein responsible for transporting oxygen in the blood. Besides its structural role in red blood cells as haemoglobin, iron plays important tasks in other essential body processes. Much of the body's iron demand is met through eating diets composed of foods from animal (heme iron) and rarely from plant (non-heme iron) sources. The inability of the body to meet its iron demand is likely to occur due to too little iron consumption or due to intake of poorly absorbed iron (non-heme iron). These shortcomings that emanate from poor quality diets are among the key determinants that contribute to anaemia in rural communities as exemplified in Kilifi County. To manage anaemia, the malaria-endemic communities of Kilifi County have resorted to using herbal medicine to alleviate sensations of fatigue, faintness, anorexia, pallor (conjunctival, nailbed, palmar or tongue), light-headedness and nausea. Consumption of herbal vegetables and/or nutri-medicinal to support recovery from anaemia is a powerful approach to health and healing and highlights the benefits of using food as medicine. It is indicative of the role that food plays in promoting health and protecting the body from illness.

Exploring the capabilities of nutri-medicinal plants used for anaemia management is important not only from a traditional claims validation point of view but also in provision of future prospects in therapeutic drug development. Assessing nutri-medicinal plants used in management of anaemia in Kilifi based on scientific available literature in addition to in vitro determination of iron and vitamin C content provides insights in to the possible mechanism of iron bioavailability. Bioavailability is a key determinant in iron absorption and assimilation. To facilitate iron absorption and assimilation, vitamin C has been reported to participate in chelation maintaining iron in the reduced ferrous (Fe^{2+}) state (Karau et al. 2012). However, it is important to note the amount of dietary vitamin C required to increase iron absorption ranges from 25 mg upwards and depends on the amount of inhibitors, such as phytates and polyphenols, present in the meal (WHO 2004).

Vitamin C is a strong antioxidant and plays an active role in iron mobilization, especially in iron deficiency cases (Fishman et al. 2000), common in anaemia of inflammation (AI) conditions. Anaemia of inflammation also known as anaemia of chronic disease is thought to occur in events of infectious diseases such as malaria, schistosomiasis, tuberculosis and HIV infections (Tolentino and Friedman 2007), whereby infected persons are reported to have poor dietary iron uptake from the gut (Spottiswoode et al. 2014). The result is a decrease in serum iron levels, as the body struggles to survive the infectious disease by en routing iron away from pathogens that could potentially exploit the circulating iron (Spottiswoode et al. 2014). The subsequent effect is that the host is rendered anaemic since iron is restricted to the erythron. It is this change in iron metabolism (accumulation of iron in granulocytes) during a malaria infection that increases a person's susceptibility to co-infections such as non-typhoidal Salmonella during malaria episodes (Spottiswoode et al. 2014). It is for this reason that iron supplementation especially in preschool children in malaria endemic regions of Africa raises concern due to increased incidences of malaria infection that escalate the risk of severe illness and even death due to malaria (Adam 2016) and bacterial infections (Cross et al. 2015). It is worth noting that malaria contributes up to 60% of anaemia cases in malaria-endemic regions of Africa (Madigu et al. 2019; WHO 2011). In this regard, the prophylactic capabilities of vitamin C that is taken alongside iron so as to increase iron uptake from the gut boosts blood haemoglobin level in iron deficiency patients who have iron restrictions synonymous to those of the malarial anaemia model (Madigu et al. 2019; Kim 2012). When they used vitamin C to increase iron bioavailability, the vitamin C-responsive group of patients experienced an increase in their serum iron levels and Transferrin Serum Iron Saturation (TSAT) scores, while the serum ferritin decreased; indicative of mobilized stored iron away from the iron deficiency state common in AI patients. With such results with the prophylactic efficacy of vitamin C, one might suggest that vitamin C adjuvant therapy may lower the risks associated with iron supplementation, which is observed to cause accumulation of iron in the gut and results in pathogenic bacterial survival and increased mortality and mortality (WHO 2007). With reported evidence of vitamin C increasing erythropoiesis in hypochromic red blood cells (HRC) (Kim 2012), new opportunities arise on how food rather than supplements can be used as medicine.

It is important to add that caution has been called for in the use of vitamin C supplements. Excess vitamin C in the body is reported to metabolize into oxalic acid. Excess oxalate accumulation leads to formation of oxalate crystal deposits in the tissues (Handelman 2007). Clinical trials using vitamin C need to be designed for short-term (90–180 days) treatment to avoid oxalosis (Handelman 2011). Exploring the use of vitamin C for anaemia treatment in cases of AI might be a worthwhile course alongside use of effective anti-malaria drugs.

8.4.3 In Vitro/In Vivo Evidence for Anti-anaemia Properties

Performing in vivo studies is crucial as it provides insights in to the potential of nutri/medicinal plants in the development of novel therapies. As a foundation of future therapeutic development, the current nutri/medicinal plants were evaluated against available literature.

***Morus alba* L.**

The *Morus alba* L. fruits' iron content of 25 mg/100 g, and vitamin C amounts of 15 mg/100 g and the fact that they are red in color, which makes them closely resemble the appearance of blood, could be the reason for their effectiveness in the cure of "low blood" mentioned by most households in Kilifi County. The red colour of *Morus alba* L. fruits occur as a result of accumulated anthocyanins that have added protective benefits (scavenge free radicals) that happen in a concentration-dependent manner (Huang et al. 2013) reducing oxidative stress commonly seen in anaemic patients. While no scientific data referred to the anaemia-healing capabilities of *Morus alba* L., the reduced oxidative stress observed may promote cell membrane integrity, and hence cell stability; a factor that could make cells evade haemolysis during a malaria attack. In addition, high antioxidant properties have been observed in *Morus alba* L. leaves' aqueous extract. For instance, evaluation of Cyanidin 3-glucoside, cyanidin 3-rutinoside and Mulberroside A, all of which are compounds found in *Morus alba* L. leaves, showed ferric reducing/antioxidant power (Wattanapitayakul et al. 2005; Chung et al. 2003). Furthermore, analysis reports of a similar plant in South Africa showed that the plant ecotype is a resourceful "super food" rich in nutrients base; carbohydrates, proteins, fibers, fats, minerals and vitamin content (Moyo et al. 2011). Since no data exist to show the positive health benefits of *Morus alba* L. in anaemia management, the indications of *Morus alba* L. as a well-thought out "functional food", as claimed in Kilifi County, remain to be explored on the bases of nutrient provision or food ingredient and/or product.

***Amaranthus hybridus* L.**

In reference to *Amaranthus hybridus* L., our study found moderate amounts of iron (13 mg/100 g), but low amounts of vitamin C content (2.41 mg/100 g) in the leaves. Our findings on low vitamin C content in this plant are similar to those reported in Burkina Faso (Nana et al. 2012), even though higher vitamin C content (13.58 mg/100 g) in a similar species has been observed elsewhere (Akubugwo et al. 2007). According to Nana et al. (2012), differences in polyphenol, including vitamin C content, are highly influenced by environmental factors as much as variations in the two methodologies was observe. The presence of anti-nutrients such as oxalates and tannins in most species of Amaranthaacea interferes with the bioavailability of the minerals that are present in the highly nutritious crop. Although cooking/boiling has been found to reduce anti-nutrients and increase bioavailability of minerals such as iron (Yadav and Sehgal 2002), the nutritional quality of a mineral in food in most cases depends on the quantity available in the plant (Reddy and Love 1999). Despite *Amaranthus hybridus* L. being popularized as food in many communities in Africa, for example, in Kenya, Burkina Faso, Nigeria, Congo and Mozambique (Mepha et al. 2007; Dhellot et al. 2012), its use in treatment of anaemia is limited due to its shortfall in increasing haematological parameters in blood (Ogbe et al. 2010).

***Moringa oleifera* (Lam.)**

Moringa oleifera (Lam.) leaves are high in iron deposits (20 mg/100 g) and vitamin C content (48 mg/100 g), suggestive of a potentially effective anti-anaemic plant.

There are times that treatment using Moringa leaves is combined with its green pods that are exemplary high in ascorbic acid (92 to 126 mg per 100 g) (Dogra et al. 1975). According to Karau et al. 2012, vitamin C improves iron absorption, enhancing iron bioavailability. The possible haematenic activity of Moringa leaves is further reinforced by a reasonably high (18.5 mg/100 g) beta-carotene content (Moyo et al. 2011). Beta carotene is the most potent precursor of vitamin A and is easily converted to vitamin A in the body of animals (Panday and Tiwari 2002). Vitamin A maintains adequate levels of iron in plasma supplying iron to different body tissues including the bone marrow where red bloods cells are synthesized (Thurber and Fahey 2009). Supplementation of diets with both iron and vitamin A has been noted to increase the iron status in an organism as measured by haematological indices like haemoglobin and haemocrit (Babu 2000). Beta-carotene-rich Moringa leaves can thus be used to release the bound iron, and thus help in reducing anaemia occurrence as well as vitamin A deficiency. In addition to vitamin A, vitamin E, which is present in the plants, assists animals to develop disease resistance (Moyo et al. 2011) as well as maintain and increase vitamin A and iron storage in the body (Moyo et al. 2011; Fuglie 2001; Anwar et al. 2007).

Vigna unguiculata (L.) Walp.)

The cowpea (*Vigna unguiculata* (L.) Walp.) is one of the most ancient food sources and has probably been used as a crop plant since Neolithic times (Summerfield et al. 1974). It has fresh young leaves, immature pods, and seeds which are sought as vegetables *(Mkunde)* in Kilifi County. *Vigna unguiculata* (L.) Walp. has relatively low iron and vitamin C content, but high protein content in the seeds and leaves, a fact that has made it be commonly referred to as a "poor man's meat" (Hamid et al. 2015). The cowpea is also rich in important vitamins, other minerals and insoluble dietary fiber (Zia-Ul-Haq et al. 2013). However, *Vigna unguiculata* (L.) Walp. contains anti-nutritional elements such as phytic acid and protease inhibitors, which can reduce the nutrition (iron) value of the crop in reference to its bioavailability (Gonçalves et al. 2016), especially because these inhibitors prevent iron absorption in plant sources. On a different note, anti-sickling activity has been noted with the use of ethanoic extracts of *Vigna unguiculata* (L.) Walp due to the presence of anthocyanins (Mpiana et al. 2009) justifying its apparent effectiveness in anaemia management.

Launaea cornuta (Hochst. ex Oliv. & Hiern) C. Jeffrey

Launaea cornuta (Hochst. ex Oliv. & Hiern) C. Jeffrey, also popularly known as *Mchunga* at the coastal region of East Africa, has an iron content of 13.5 mg/100 g but relatively low vitamin C content. There is no scientific proof at present to establish the capability of its aqueous extracts in increasing haematological parameters. Nonetheless, positive results have been seen with the use of ethyl acetate extracts in anaemia treatment (Khan et al. 2016).

Zanthoxylum chalybeum Engl.

Zanthoxylum chalybeum Engl., commonly known as *Mndungu* (local in the language) in Kilifi County, had relatively low iron and vitamin C contents. Although limited data is available to show the use of this nutri/medicinal plant in anaemia treatment, its use in malaria management is well documented (Bbosa et al. 2014; Patiño et al. 2012; Nguta et al. 2010a, b), implying its indirect use in anaemia management.

Vernonia microcephala DC.

Another medicinal plant *Vernonia microcephala* DC. is commonly referred to as *Muboho* in Kilifi County, where it is used in the treatment of anaemia in a number of households, but has no scientific data to support its use as an anti-anaemic.

Grewia densa K. schum

Grewia densa K. schum, popularly known as *Mkone* in Kilifi County of Kenya, is a common tree in Kilifi with the fruits being seasonal, hence limiting its use in traditional medicine. *Grewia densa* K. schum leaves are rich in vitamin C (20.76 mg/100 g); an amount that could be suggestive of its potential in maintaining cells' integrity following oxidative stress caused by parasitic infection such as malaria. In terms of existing literature, no available scientific findings support its treatment of anaemia and/or malaria.

Lannea schweinfurthii Engl.

Lannea schweinfurthii Engl. *Mnyumbu* (local name), which is traditionally used as medicine in Kilifi County in the management of anaemia has no scientific information available to establish its use as an anti-anaemic.

Kigelia africana (Lam.) Benth.

Kigelia africana (Lam.) Benth. (Bignoniaceae) is a tree endemic with roots that are rich in vitamin C content 27.87 mg/100 g. The seeds and fruits are widely employed in food processes as well as in the indirect management of anaemia through malaria treatment. While several experiments using plant extracts and isolated compounds of *Kigelia africana* (Lam.) Benth. provide meaningful justification of its use as an antioxidant. Antioxidants inhibit oxidation and protect body cells from oxidative damage. There is need to be conduct clinical studies of isolated compounds to get potential candidates for anaemia treatment; the process will allow the results that show high percentage of potential antioxidants, medically important phytochemicals and good quantity of nutritional qualities be validated and exploited for anaemia prevention/treatment/management (Oseni and Dada 2018). In addition, it will approve reports such as that of 2,2-diphenyl-1-picrylhydrazyl (DPPH), total phenolic content, total flavonoid, ferric reducing antioxidant power (FRAP), phytochemical constituents, proximate and mineral elements compositions that highlight the high antioxidant capabilities in fruits.

Cassia occidentalis L.

Cassia occidentalis L. has an iron content of 14.3 mg/100 g and the highest vitamin C content of 50.25 mg/100 g) of all the plants sampled only comparable to pepper (50.04 mg/100 g) which is considered highest of all the nutri/medicinal plants consumed by man. The findings are in agreement with those from the X-ray fluorescence spectrophotometry that show that *Cassia occidentalis* L. is rich in iron

(11%–15%) and has the potential to relieve iron deficiency in local communities (Manikandaselvi et al. 2016). The WHO recommends iron content be in the range of 70–200μg/g ~ 7–20 mg/100 g for any plant to be considered for potential haematenic activity (WHO 2001). Even though *Cassia occidentalis* L. was not the most frequently mentioned nutri/medicinal plant in the concluded household survey, the indications of high iron content and significant quantities of vitamin C compounded with proposed complete recovery after a short (one week) duration of treatment (Table 8.3) increase the potential of *Cassia occidentalis* L. in treating anaemia of inflammation (AI) in the malaria-endemic region of Kilifi County. Anaemia of inflammation, which mainly occurs in malaria-endemic areas, may require vitamin C as a component to mobilize available iron to avert the anaemic state (Kim 2012). Besides vitamin C, *Cassia occidentalis* L. has high antioxidant and ferrous ion chelation properties that make it superior in scavenging for radicals (Yadav et al. 2010).

8.4.4 Availability of Anti-anaemic Functional Foods

The study sought to assess whether traditional medicine is a reasonable community resource. We noted that approximately 95% of the perceived anti-anaemic traditional medicinal plants mentioned in the malaria-endemic region of Kilifi County were readily available, suggestive of a practical community resource and probably the most preferred option for patients. As a reasonable community resource, most medicinal plants are cultivated with only a third being collected from the wild. The most cultivated medicinal plants were consumed as fruits or vegetables while those harvested from the wild were mainly trees that take long to grow when cultivated and/or the seedlings to the trees have reduced chances of survival when cultivated. Approximately 10% of the plants were bought from the neighbours' farms with very few being imported from different regions.

Conventionally, *Zanthoxylum chalybeum* Engl. and *Vernonia microcephala* DC. were among the medicinal plants whose bark and roots were harvested from the wild. Harvesting the root and bark of a medicinal plant as opposed to the leaves is not sustainable mainly because it destroys the plant eventually leading to its extinction (Bbosa et al. 2014). For some plants, the leaves were used for treatment of anaemia. Some of these include *Grewia densa* K. Schum and *Kigelia africana* (*Lam.)* Benth. Use of leaves did not threaten the survival of the species. *Kigelia africana* (Lam.) Benth., for example, is abundant across the wet Savannah *and has a long history of use as food and medicine by rural people in many other African countries* (Saini et al. 2009; Cragg and Newman 2001). *Therefore, Kigelia africana* (*Lam.)* Benth. a *suggested by name (Africa), has connection with its location, orientation and association including with other plants* (Saini et al. 2009). In many parts of rural Africa, the rural communities have an inclination towards using traditional medicine possibly because it is an affordable, accessible and culturally acceptable source of primary healthcare that is available. The communities may lack modern health facilities and effective pharmaceutical therapeutic remedies; as a result there remains an active need to perform familiar cultural traditional medicine practices that are passed on from one generation to the next.

8.4.5 Clinical Evidence for Anti-anaemic Properties and Cytotoxicity Considerations of the Plants Named by the Respondents

Inhabitants of most developing countries use traditional medicinal plants obtained from empirical practices to alleviate, prevent and/or cure illness common in their environment. Even though herbal plant medicines are often perceived to be safer than allopathic drugs, the natural origin of plant products does not exempt them from potential toxicity in humans. It is for this reason that studies to substantiate and evaluate potential clinical efficacy, possible side effects and toxicity are imperative. We examine literature for available clinical evidence of anti-anaemic potential and possible cytotoxicity that occur upon use of the various nutri/medicinal plants frequently mentioned in Kilifi County.

Morus alba L.

Based on our study, *Morus alba* L. was the most frequently mentioned nutri/medicinal plant in the management of anaemia in Kilifi County. In reference to clinical experiments carried out, *Morus alba* L. had no effect on haematological parameters. While there is no scientific evidence connecting *Morus alba* L. to treatment and/or management of anaemia, animal models show enhanced natural cognition, neuroprotection and decreased oxidative stress in the hippocampus region of the brain (Kaewkaen et al. 2012). Noting that poor cognitive function and fatigue occurs in children suffering from anaemia (Chen et al. 2013; Sumbele et al. 2013), *Morus alba L.* comes in handy. A recent revelation that iron supplementation in anaemic individuals leads to an increase in morbidity and mortality as a result of bacterial infections makes us speculate that *Morus alba* L. may have great potential as antimicrobial agent with prospects of being rich in iron. It is this connection of *Morus alba* L. to having strong antimicrobial properties, for instance, prebiotics such as fructooligosaccharide- 1 ketose and nystose aspects (Dimitrova et al. 2015), that makes us hypothesize that *Morus alba* L. has high capabilities in protecting the body against disease causing microorganisms. So, once iron is assimilated in the body, any prospective bacteria that occurs during the supplementation period is wiped out. In this regard, there exists an opportunity to explore the capabilities of this nutri-medicinal plant to treat anaemia.

Morus alba L. fruits, leaves and roots are reported to have cytotoxicity and anticancerous bioactive constituents. For instance, anthocyanins from *Morus alba* L. have been found to reduce migration and invasion of carcinoma cells in the human lung (Chen et al. 2006), inhibit melanoma cells growth (Huang et al. 2008) and could be of great value in developing future potential cancer therapy. A group of flavonoids isolated from *Morus alba* L. leaves like the Moracins are potent against human cervical, breast and hepatic carcinoma cells (Dat et al. 2010), whereas Chalcone derivatives were noted to be cytotoxic against human gastric gland carcinoma cells (Yang et al. 2010). New 2-arylbenzofuran derivatives of Moracins and Morachalcones have also been found to exhibit varying cytotoxicity against several human cancer cells lines (Yang et al. 2010). Collectively, extracts of *Morus alba* L. could be considered safe, and the results support the application of its use as novel food ingredient or product.

Amaranthus hybridus L.

Amaranthus hybridus L. was the second most frequently mentioned nutri/medicinal plant for controlling anaemia. Clinical indications show that the aqueous leaf extract of *Amaranthus hybridus* L. had minimal ($P < 0.05$) anti-anaemic effect in rabbits (Ogbe et al. 2010). Treatment of EAC cells with lectin-rich *Amaranthus hybridus* L. seed extract inhibited the growth of cancer cells by induction of apoptosis (Al-Mamun et al. 2016). However, the complete mechanisms underlying the therapeutic effects of the extract (cytotoxicity) need to be investigated future (Al-Mamun et al. 2016).

Moringa oleifera Lam.

Moringa oleifera Lam. was the third most frequently mentioned nutri/medicinal plant in Kilifi County in anaemia management. The clinical use of Moringa in the management of anaemia has been found to be effective in reducing moderate anaemia in children especially when used for a long time (Shija et al. 2019; Suzana et al. 2017). In addition, studies performed in animal models have shown an increase in iron status following administration of Moringa leaves (Babu 2000). The increase in the haematological parameters is attributed to not only high iron content but also high vitamin C that influences the bioavailability of iron and the readily converted vitamin A together with vitamin E (Panday and Tiwari 2002; Thurber and Fahey 2009). Vitamin A deficiency is among the factors that contribute to severe anaemia that occurs in about one-third of the severely anaemic African adults and children (van den Broek and Letsky 2000; Mehta et al. 2010). Therefore, noting the role of vitamin A, supplementation by Moringa extracts could reduce susceptibility to malaria and bacterial infection; the key contributors of severe anaemia (van Hensbroek et al. 2011). *In reference to cytotoxicity, Moringa oleifera L.* extracts may represent a valuable therapeutic approach for aggressive breast, liver and colorectal carcinomas (Al-Asmari et al. 2015). The *Moringa oleifera L.* extract activates anti-tumour potential by interfering with oncogenesis, cancer cell growth and progression (Tiloke et al. 2013).

Vigna unguiculata (L.) Walp.

Vigna unguiculata (L.) Walp. is a common vegetable in Kilifi County considered to be useful in the management of anaemia, and like for many other legumes, cowpeas are well-known due to their ascribed nutritional and medicinal properties. Scientifically, the seeds have been found to have high protein content and are used to prevent protein malnutrition that emanates from poor quality proteins (Zia-Ul-Haq et al. 2013). The improved protein quality could prevent the occurrence of dietary iron deficiency anaemia. No clinical studies have been published in reference to the use of *Vigna unguiculata* (L.) Walp. in the management of anaemia and in the treatment of cancerous cells.

Launaea cornuta (Hochst. ex Oliv. & Hiern) C. Jeffrey

Community members use *Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey to control anaemia in Kilifi Country. Clinical indications show that oral administration of aqueous leaf extracts of *Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey altered the red blood cell count, haemoglobin levels, packed cell volume, mean cell hemoglobin concentration and mean cell volume, but did not increase haematological parameters in mice (Muriira 2014). On the other hand, whole plant methanolic extract of *L. cornuta* (at dose 20μg/mL) possessed minimum haemolytic activity, whereas the ethyl acetate extract (at dose 100μg/mL) possessed highest haemolytic activity (9 ± 0.35) of the doses with the haemolytic percentage increasing with increase in dose (Khan et al. 2016). In a different note, cytotoxicity against brine shrimp (Musila et al. 2013) as well as in vitro anti-cancer activities have been reported in different studies (Onyancha et al. 2015).

Zanthoxylum chalybeum Engl.

Zanthoxylum chalybeum Engl. is among the most frequently mentioned nutri/medicinal plant for management of anaemia in Kilifi County though its use may be linked to malaria more than anaemia (previous discussed in Sect. 8.4.1). Clinical indications show *Zanthoxylum chalybeum* Engl. has effective anti-malarial properties (Nguta et al. 2010a, b; Patiño et al. 2012; Bbosa et al. 2014). The ether and methanolic leaf extracts of *Z. chalybeum* Engl. contain secondary metabolites with anti-plasmodial activity (Bbosa et al. 2014) suggestive of an effective plant in malaria and helminthes control. Other indications show *Z. chalybeum* Engl. is effective in malaria and/or sickle cell anaemia control suggesting an indirect role of *Z. chalybeum* Engl. in anaemia management. Although no scientific evidence in humans exists that warrants *Z. chalybeum* Engl. use in treatment of sickle cell anaemia, long-term low doses of the root-bark extract have been noted to be safe in experimental animals (Engeu et al. 2008). High doses, however, have been found to have dose-dependent toxicity effects. This observation may contribute to the varied reports witnessed on the use of *Z. chalybeum* extracts with reference to cytotoxicity. Aqueous and organic extracts of *Zanthoxylum chalybeum* Engl. (IC50 value of 3.65μg/ml) exhibited strong cytotoxic activity (Nguta et al. 2012). On the other hand, Tuasha et al. (2019) found various extracts of *Z. chalybeum* not to be cytotoxic (IC50) at concentrations below 1μg/ml in the human breast cancer cell lines even as the essential oil from *Z. chalybeum* was noted to be the most cytotoxic (Ocheng et al. 2016).

Kigelia africana (Lam.) Benth.

Kigelia africana (*Lam.)* Benth. is frequently used as a nutri/medicinal plant in Kilifi County for management of anaemia. It is best known as cucumber or sausage tree because of the huge fruits (average 0.6 m in length and 4 kg in weight) that hang from long fibrous stalks (Saini et al. 2009). It is famous in the Kilifi County of

Kenya, where it goes by the name *Mnyahi. Mnyahi* leaves are used as vegetables; the fruits provide a palatable salad delicacy while the root is ground and the filtrate drank for treatment of anaemia. As indicated by the people of Kilifi, energy tended to resume after its consumption; which may serve as an indication of its effectiveness in increasing the amount of blood in the body. T*raditionally, its medicinal properties are thought to be due to its perceived characteristics such as bitterness, astringent taste or smell* (Saini et al. 2009). *Kigelia africana* (*Lam.)* Benth. seems to be anti-malarial rather than anti-anaemic, and therefore the action observed in anaemic patients may be an indirect activity from effective a*nti-malarial* properties obtained by virtue of the compounds present in the plant (Binutu et al. 1996*; Weiss* et al. 2000 and Saini et al. 2009). *While the plant could have haematenic potential,* in vivo *and* in vitro *tests are yet to be carried out.* The plant extract is also found to be safe even at high concentrations, and has been observed to possess strong anti-cancer properties (Sri Sainadh et al. 2013; Olatunji and Olubunmi 2009). It is also a strong antioxidant with enhanced wound healing properties justifying its medicinal use in treatment of microbial infections and wounds (Agyare et al. 2013).

Cassia occidentalis L.

Cassia occidentalis L. is locally referred to as *"Mtsalafu"* in Kilifi County while in other settings it is referred to as *Senna occidentalis* L. It is among the nutri/medicinal plants used for management of anaemia in Kilifi County. In reference to clinical use, oral administration of *S. occidentalis* leaf ethanoic extracts possessed anti-*T. brucei* activity that ameliorated disease-induced anaemia (trypanosome-induced anaemia) and organ damage (Ibrahim et al. 2010). In a different study, consumption of *C. occidentalis* relieved iron deficiency in a local community with advocacy on the use of the medicinal plant as a dietary supplement to treat anaemia being proposed (Manikandaselvi et al. 2016). A more indicative study shows *Senna occidentalis* L. possesses haematinic activity (erythrocytes counts and haemoglobin concentration) in experimental animals (Madigu et al. 2019; Adedapo et al. 2009). In addition to positive haematological shifts, all experimental animals showed accelerated recovery with excellent response being noted in white blood cell counts (WBC) and its differentials, red blood cell (RBC) count, packed cell volume (PCV) and haemoglobin (Hb) concentration (Madigu et al. 2019; Adedapo et al. 2009).

Although results showed that acute or subacute administration of *Cassia occidentalis* L. is not toxic in male and female Wistar rats, suggesting safety margin for use by humans (Silva et al. 2011), contrasting results in reference to toxicity were noted with the use of high doses (2500 mg/ Kg bw/day) of *Cassia occidentalis* L. in prophylactic experiment (Madigu et al. 2019). In reference to cytotoxicity, it has been observed that aqueous extract of *C. occidentalis* L. (whole plant) has more potential than hydro-alcoholic and alcoholic extracts against HCT-15, SW-620, PC-3, MCF-7, SiHa and OVCAR-5 human cancer cell lines at 100, 30 and 10μg/ml portraying a dose-dependent curve (Bhagat and Saxena 2010).

Other Nutri/Medicinal Plants

Diversity in nutria/medicinal plants used in anaemia management may just highlight the various etiologies that cause anaemia. Evaluating clinical data is important to ascertain the capabilities of the plant in anaemia management. We found no clinical scientific data that supports the use of either *Vernonia microcephala* DC or Grewia *densa* K. schum, (popularly known as *Mkone* in Kilifi County) as an anti-anemic and /or anti-malarial medicinal plant. As food, *Grewia densa* K. schum has been mentioned as a fruit for monkeys, while *Lannea schweinfurthii* Engl. showed anti-plasmodial, anti-trypansosomal and antioxidant activity, all of which are associated with management of anaemia indirectly. Additional detailed ethnopharmacological studies emphasizing on the need of clinical and toxicological evaluations to assess efficacy and safety of these species as herbal medicine (Maroyi 2017).

8.4.6 Conclusions and Recommendations

The prevalence of anaemia is noted to be high in Kilifi County evident by the high number of the households that had experienced anaemia in the past. Majority of the households preferred the use of herbal medicine; a reliable community resource in anaemia management. From this study, the most frequently mentioned nutri/medicinals in Kilifi County for anaemia management include: - *Morus alba* L. and *Amaranthus hybridus* L. Others were *Moringa oleifera* Lam., *Vigna unguiculata* (L.) Walp., *Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey and *Zanthoxylum chalybeum* Engl. The least frequently mentioned but the most effective nutri-medicinal plants were *Kigelia africana* (*Lam.)* Benth. and *Cassia occidentalis* L. Most herbal medicine/medicinal plants hailed for their medicinal properties in Kilifi County are either fruits or vegetables with nutri/medicinal potential to treat anaemia indirectly. Collectively, available scientific data supported the application of *Morus alba* L. and *Moringa oleifera* Lam. use as novel food ingredient or product. More clinical studies need to be carried out on the possible safety and efficacy of the different nutri/medicinal plants extract.

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Chapter 9
Plantain Bioactives: An Underutilised Food Resource in Africa

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9.1 Introduction

Plantains and bananas are members of the *Musa* genus and are among the world's foremost fruit crops. As of 2022, 43.12 and 119.8 million metric tons of plantains and bananas were produced globally (Shahbandeh 2022). China, Indonesia, Brazil, and Ecuador are the leading producers of bananas and plantains worldwide (Shahbandeh 2022). In African countries, especially in Nigeria, plantain is among the commonly consumed and important food crops along with rice, maize, and wheat. Plantains are also popular, particularly due to the fact that they can be consumed in various ways and at different stages of ripening, depending on individual preferences (Fig. 9.1). Plantains are consumed at various stages of ripening, that is, unripe, fairly ripe, ripe, and overripe stages. They can be eaten raw, boiled, grilled, or fried (Oladele 2013).

Both the pulp and peel of plantains contain good quantities of nutritional and bioactive components. These include carbohydrates such as hemicellulose, starch (resistant and digestible), pectin, lipids (rich in polyunsaturated fatty acids), proteins, vitamins, and minerals, for example, sodium, potassium, calcium, and magnesium, as well as carotenoids, flavonoids, and polyphenols (Aurore et al. 2009).

It is unfortunate that a large number of plantains produced annually in Africa are lost to wastage, while consideration for industrial processing is little. In Africa, the processing of plantain and banana into flours, dried pulps, chips, jam, spirits, and other useful products, is growing very slowly (Emaga et al. 2007). Plantain pulp is a good source of starch, indigestible carbohydrates (resistant starch, soluble and

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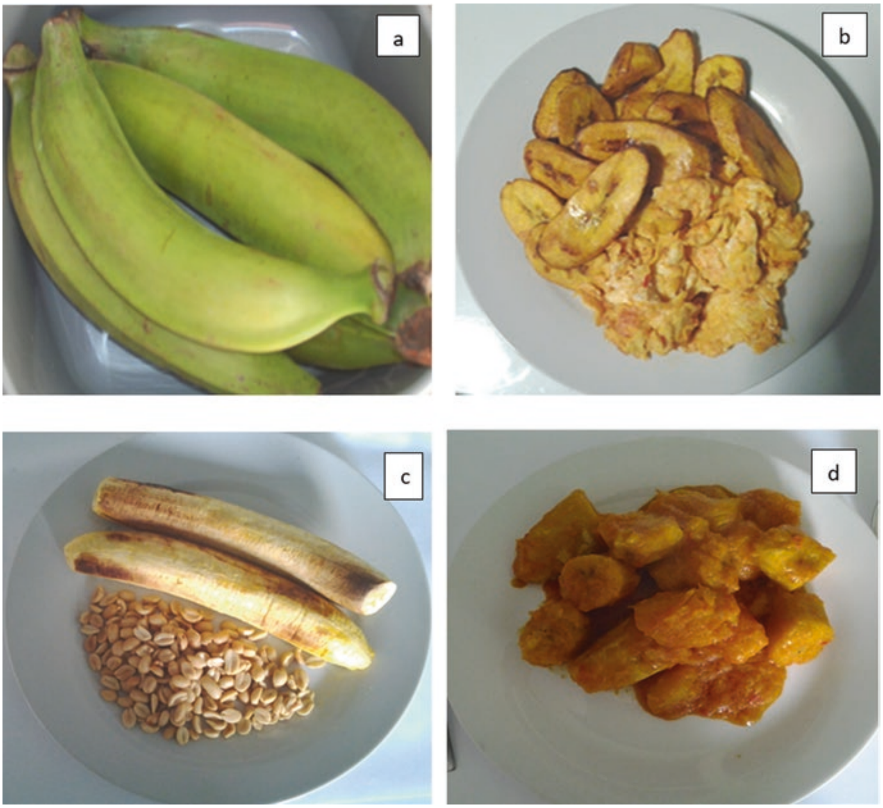


Fig. 9.1 Pictures of plantain cultivars and processed plantain foods. (**a**) Unripe plantain fingers. (**b**) Fried ripe plantain with omelette meal. (**c**) Grilled unripe plantain with roasted groundnuts. (**d**) Unripe plantain cooked with red oil, spices, and sauce. (Adapted from Oladele 2013)

insoluble fibre), and polyphenols. Dietary fibre accounts for a large number of bioactive substances present in plantains and is referred to as the main antioxidant component of plantains (antioxidant dietary fibre). Most of these substances have been linked with the prevention/management of chronic degenerative diseases (Bello-Pérez and Agama-Acevedo 2019). In addition, a study shows the consumption of plantains for the treatment/management of type 2 diabetes (Bello-Pérez and Agama-Acevedo 2019).

Dried unripe plantains prepared in different ways have been found to be effective both as prophylactic and curative treatment of aspirin-induced ulcers in rats. This therapeutic property was assessed against some other substances with established anti-ulcerogenic activity such as aluminium hydroxide, cimetidine, prostaglandin E2, and *N6,2′-O-Dibutyryladenosine 3′,5′-cyclic monophosphate.* It was discovered that they exhibited anti-ulcerogenic activity when used as a prophylactic agent in rats. However, they were not efficacious in healing ulcers already formed by aspirin. Furthermore, these other substances did not stimulate the growth of gastric mucosa.

It was subsequently deduced that the anti-ulcerogenic actions of the plantain preparations were due to their abilities to stimulate the growth of gastric mucosa (Lewis et al. 1999).

Clinical trials also revealed that green plantain had a beneficial effect in the dietary intervention of persistent diarrhoea in hospitalised children in relation to diarrheal duration, weight gain, and costs. However, these prophylactic effects were lost when plantains were cooked (Alvarez-Acosta et al. 2009).

Despite the huge evidence of a large number of bioactive substances present in plantains, it is unfortunate that very few functional foods and functional food ingredients from plantains have been exploited for industrial food/nutraceutical production. There is a need for the food industry to annex all available information regarding plantain bioactives to maximise the salutary effects of plantains in terms of nutritional and biological effects in solving the current and ravaging worldwide problem of food and nutrition security as well as health-related diseases.

This is particularly important in Africa, where poverty is a menace, and the cost of imported drugs is barely affordable by the common man. This chapter intends to bring together information on the significant bioactive substances in plantains to develop a holistic approach into possible and quick utilisation of the information contained therein for the promotion of health and nutrition in Africa and ultimately in the world at large.

9.2 Resistant Starch and Glycaemic Index (GI) of Plantain

It is no longer news that it is not the entirety of starch ingested that is fully digested and absorbed in the human small intestine. A part of the starch in some foods, such as cereals, potato, and banana, escaped digestion and were recovered in effluents collected from ileostomies (Englyst and Cummings 1985, 1986).

.There are five types of resistant starches that are recognised on the grounds for which starch may evade digestion in the human small intestine (Englyst and Kingman 1990; Brown et al. 1995). These are as follows:

RS1 – physically inaccessible starch
RS2 – resistant starch granules
RS3 – retrograded starch
RS4 – resistant starch produced by chemical modification
RS5 – amylose-lipid complex.

In addition to resistant starch, another starch fraction, namely, slowly digestible starch (SDS), which represents the portion of starch digested between 20 and 120 minutes of starch ingestion, has also been shown to have some physiological benefits. SDS elicits a moderate postprandial glycaemic and insulinemic response and has been studied and found useful for the dietary management of chronic and metabolic conditions, mainly type 2 diabetes and hyperlipidaemia (Aller et al. 2011).

Resistant starch has the advantage that it escapes digestion in the human gastrointestinal tract; therefore, foods high in resistant starch have extremely low digestibility (Butardo and Sreenivasulu 2016). RS also performs a biological role similar to dietary fibre due to the fact that it makes available a substrate for the microbial fermentation of short-chain fatty acids (SCFAs) in the human digestive system. Resistant starch does not increase the caloric content of foods since it is not digestible (Asp 1997).

9.2.1 Resistant Starch and Other Starch Fractions in Plantain

Englyst and Cummings (1986) were the first to discover enzyme resistant starch in *Musa* spp., when up to 90% of ingested starch content of banana was recovered in effluents from ileostomies. Resistant starch values of 66.7%, 10.5%, and 3.9% of total starch were also reported for freeze-dried samples of raw, freshly cooked, and cooked and reheated green plantain, respectively, in vitro (Englyst and Cummings 1986). The granule structural characteristics and starch degradation patterns of plantain and banana indicate that plantain starch is more resistant to digestive enzymes than banana starch (Soares et al. 2011).

Plantain is rich in both resistant starches and slowly digestible starches, depending on whether it is cooked or uncooked, ripe or unripe, as well as the condition of processing. Pelissari et al. (2012) and Ovando-Martinez et al. (2009) reported a resistant starch (RS2) value of 42.5 ± 0.4 to 50.3 ± 1.0 g/100 g sample (DWB) for raw green plantain flour and starch, respectively.

Oladele and Williamson (2016) reported the results in Table 9.1, showing various types of resistant starches in three different plantain products fed to healthy participants on a study on the glycaemic index of plantains. The varying levels of RS1, RS2, and RS3 reported stimulates great attention. In the food portion size tested (which represents 25 g available carbohydrates), resistant starch (RS) was not detected in boiled unripe plantain crisps (BUPC), whereas RS content was 2.0 ± 0.9 and 20.8 ± 1.9 for boiled unripe plantain (BUP) and ripe, raw plantain (RRP), respectively. Slowly digestible starch (SDS) values of 9.8 ± 0.7, 0.0 ± 0.1, 0.2 ± 0.3

Table 9.1 Resistant starch content of some plantain products

	RS1	RS2	RS3	Total RS
BUP	2.0 ± 0.9	ND	ND	2.0 ± 0.9
BUPC	ND	ND	ND	ND
RRP	3.4 ± 1.2	17.4 ± 2.3	0.0	20.8 ± 1.9

Obtained from Oladele and Williamson (2016)
This table gives breakdown of types and quantities of resistant starch present in three plantain products; boiled unripe plantain (BUP), boiled unripe plantain crisps (BUPC) and ripe raw plantain (RRP). *ND* not detected, *RS1* inaccessible starch, *RS2* native resistant starch, *RS3* retrograded starch. Results represent quantities in 25 g available carbohydrate food portion sizes and are expressed as means ± standard deviations, $n = 3$

and 0.1 ± 0.2 for the same food portion size was also reported for BUP, BUPC, RRP, and WB (white bread), respectively, in the same study. One of the popular ways of consuming plantains in Nigeria is to have them steamed/boiled. Boiled ripe and unripe plantains cooked with and without salt contain significant quantities of resistant starch and slowly digestible starch (Oladele 2016), and therefore could be particularly good dietary interventions for the management of type 2 diabetes. It should be noted, however, that unripe plantains contain higher values of RS1, RS3, and total RS than their ripe counterparts, probably as a result of higher starch content.

Plantains cooked with no salt (NS) had RS3 values, which were not significantly different ($p \leq 0.5$) after 24 and 48 h storage. The addition of salt during cooking increases the quantity of RS3 by about 66–113% between 24 and 48 h for both ripe and unripe plantain (Oladele 2016).

Resistant starch type 3 (RS3) has attracted great attention on the assertion that it is the most prevalent type of resistant starch present in processed foods (Björck et al. 1987). RS3 appeared not to have been prominent in plantains initially due to the conspicuous presence of RS2, as *Musa* spp. are among the few sources of resistant starch type 2. Moreover, starch in the *Musa* spp. was initially assumed to have poor retrogradation properties, which was later to be untrue for plantain, especially when starch retrogradation is studied in situ (i.e. within the food matrix). Plantain foods have the potential for the generation of retrograded resistant starch (RS3), and this important attribute should not be ignored but explored in the production of functional foods (Oladele 2016).

Plantain, especially unripe plantain, is also rich in resistant starch type 1 (R1) (Oladele 2017). RS1 has only been reported in partly milled seeds, grains, and whole-grain foods as well as in some very dense types of starchy foods, for example, pasta. Resistant starch type 1 is generated when starch is physically entrapped inside the food matrix. The inability of digestive enzymes to physically access starch occurs whenever starch is held in food pieces that have not been completely broken down (Neil et al. 2005). The presence of RS1 in foods appears to contribute to a slower digestibility due to a denser food matrix as well as the inaccessibility of digestive enzymes. This important bioactive property should be explored to curb the increasing incidence of obesity and related conditions.

9.2.2 Glycaemic Index of Plantains

The glycaemic index (GI) is a means of classifying foods based on their effects on blood glucose levels. The concept was developed over 30 years ago by Jenkins and Wolever (1981) with the initial aim of facilitating the control of postprandial hyperglycaemia in diabetic patients. However, today, the consumption of healthier foods with low GI is becoming more popular due to the rise in cases of obesity and related conditions.

The glycaemic index classifies each food according to its postprandial rate of carbohydrate digestion and glucose absorption. It is the incremental area under the postprandial blood glucose curve after the consumption of 50 g of (digestible) carbohydrates from a test food, divided by the area under the corresponding curve after the consumption of 50 g of (digestible) carbohydrates from a reference food (Wolever et al. 1991). The reference food, which is usually white bread or glucose, is given a value of 100 (Wolever 2006).

Plantain has long been classified as a low GI food. There is overwhelming evidence of the therapeutic potential of low-glycaemic index diets in the management of diabetes, hyperlipidaemia, and cardiovascular diseases (Jenkins and Wolever 1981; Jenkins et al. 1987; Augustin et al. 2002).

Low GI foods have been associated with positive impacts on a wide variety of chronic diseases, such as diabetes, obesity, and coronary heart disease (Chiu et al. 2011; Brand-Miller et al. 2009). This is because lower blood glucose and insulin levels have been linked to an improved metabolic profile of high-density lipoprotein cholesterol, glycosylated proteins, oxidative status, haemostatic variables, and endothelial function.

There is a growing interest in the consumption of resistant starch (RS) rich foods due to the potential health benefits, particularly hypoglycaemic impact, derivable from them. The consumption of food products rich in RS has been associated with a low postprandial glucose and insulin response for over 20 years (Oladele 2013).

The studies in Table 9.2 indicate that plantains have low to medium GI values according to the generally accepted classification by Brand-Miller et al. (2009). Plantains can be processed into their various forms before consumption in order to increase palatability and extend shelf life. These processed plantains have been shown to affect the glycaemic indices of plantains, thus altering the hypoglycaemic properties on plantains, especially unripe plantain (Brand-Miller et al. 2009; Kazhila and Chinsembu 2019). Plantain has been listed as one of the plant foods for the treatment/management of diabetes, not only for component polyphenols but also for low glycaemic index (Kazhila and Chinsembu 2019). The GI of bananas is more commonly reported because plantain is favourably eaten cooked because of its higher starch content. The GI of uncooked ripe plantain obtained here (38.5 ± 4.4, n = 10, mean ± SEM) is lower than an average GI of 52.0 ± 4.0 obtained from ten studies on bananas (Foster-Powell et al. 2002). Plantain glycaemic index is reduced by the presence of resistant starch and slowly digestible starch, but these are not the only contributors to the low values of plantain glycaemic index.

Plantain, especially unripe plantain, has a dense structure as well as reasonable quantities of polyphenol substances, which may also have an impact on its low glycaemic index. Homogenising the plantain pulp destroys the food form and reduces the glycaemic index. Gelatinisation also contributes to a lower glycaemic index because starch becomes more soluble. However, in cooked and cooled foods, the formation of retrograded starch (RS3) can contribute to a lower glycaemic index (Oladele 2013). Plantains are usually consumed with condiments, as indicated in studies 3 and 4; this may have an impact on the GI depending on what condiments are used.

Table 9.2 Reported studies on the glycaemic index of plantain

Study	Products used	Food portion size (g)	Size basis	Subjects	Ref food	Reported GI	Reference
1.	(a) Unripe banana mass-cooked pulp of unripe banana (b) Unripe banana starch – starch isolate (un-gelatinised)	(a) 81 (b) 59	50 g TS	9	White bread	(a) 43.2 (b) 6.4	Menezes et al. (2010)
2.	(a) Boiled green plantain (b) Boiled ripe plantain (c) Fried green plantain. (d) Fried ripe plantain	(a) 259.2 (b) 308.6 (c) 175.9 (d) 211.6	50 g AV CHO	10	Glucose	(a) 39 ± 4 (b) 66 ± 2 (c) 40 ± 3 (d) 90 ± 6	Bahado-Singh et al. (2006)
3.	Boiled green plantain with stew and meat	50	No basis	D-9 H– 7	Glucose	(a) 68 (b) 69	Alegbejo and Ameh (2012)
4.	(a) Boiled plantain with soup and meat (b) Roasted plantain (c) Fried plantain (d) Boiled and pounded plantain (e) Cooked plantain flour meal	(a) 124.4 (b) 224.4 (c) 62.9 (d) 138.2 (e) 121	50 g AV CHO	50 for samples, another 10 for reference	Glucose	(a) 64.9 ± 10 (b) 56.9 ± 9 (c) 64.9 ± 9 (d) 66.6 ± 3 (e) 65.1 ± 1	Godwin and Oboh (2010)
5.	Green plantain powder in 125 ml water (meringue)	Not given	50 g AV CHO	10	Glucose*	39	Pacheco-Delahaye et al. (2004)
6.	Boiled green plantain	120	21 g AV CHO	8	Glucose	38 ± 10	Perry et al. (2000), Atkinson et al. (2008)
7.	(a) Boiled unripe plantain (BUP) (b) Boiled plantain crisps (BUPC) (c) Ripe, raw plantain (RRP)	125 32 163	25 g AV CHO	10	White bread	(a) 44.9 ± 6.7 (b) 55.0 ± 7.9 (c) 38 ± 6.9	Oladele (2013); Oladele and Williamson (2016)

(continued)

Table 9.2 (continued)

Study	Products used	Food portion size (g)	Size basis	Subjects	Ref food	Reported GI	Reference
8.	Charcoal-roasted plantain (unripe) Fried plantain (ripe) Fried plantain (overripe) Chips plantain (unripe)	123 99 97 94	50 g AV CHO	30	Glucose	(a) 88 ± 1.8 (b) 39 ± 0.3 (c) 39 ± 0.5 (d) 45 ± 0.3	Kouamé et al., (2017)

Adapted from Oladele (2013)
CHO carbohydrate; *AV* available Study 3: *D* diabetic; *H* Healthy; Study 5: glucose* – commercial solution

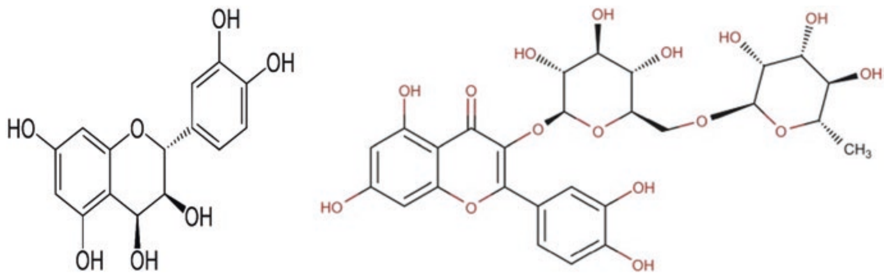
9.3 Polyphenols in Plantain

Phenolics are a group of phytochemicals that contain a phenol structure (an aromatic ring containing several hydroxyl groups) (Manach et al. 2004). Their fame in research is due to their numerous health benefits and contribution to the mitigation of a wide range of chronic and cardiovascular diseases, such as hypertension, cancer, diabetes, skin damages, allergies, atherosclerosis, and viral infections (Da-Wei and Szu-Chuan 2012; Liu 2004). As a result of all these potential benefits, plant phenolics are used in the formulation of dietary supplements, food additives, drugs, etc. Moreover, polyphenol-rich foods are also introduced as dietary supplementations in the therapeutic management of chronic diseases.

In Nigeria and Africa as a whole, every part of the plantain has been utilised in folklore medicine. It has been studied and shown to possess antioxidant, antibacterial, anti-ulcerogenic, anti-hypertension, antidiabetic, and anti-cancer activities (Imam and Akter 2011).

The plantain (unripe pulp) contains a natural flavonoid known as leucocyanidin (Fig. 9.2), which is extractable from unripe plantain via solvent fractionation. This flavonoid has been shown to protect the gastric mucosa from erosions caused by the intake of aspirin (Lewis et al. 1999).

Plantain pulps and peels contain a high level of phenolics and hydroxycinnamic acids (Fig. 9.3). Ferulic acid-hexoside, especially with a dry weight of 4.4–85.1 mg/g, is predominant in the plantain pulp. These values, however, vary from one cultivar to the other. Flavonol glycosides are the most prevalent flavonoids in plantain peels; rutin (Fig. 9.2), which is the most abundant, ranges between 242 to 618.7 mg/g DWB (dry weight basis) (Claudine et al. 2015).



Leucocyanidin Rutin

Fig. 9.2 Structures of some phenolics found in plantain

9.3.1 Nutraceutical Properties of Plantain Polyphenols

Plantain has been shown to possess anti-ulcerative properties. It does this by increasing the thickness of the mucosa layer, lessening the severity of stomach ulcers. However, it does not inhibit the secretion of gastric acid (Best et al. 1984).

Dried powdered unripe plantain was shown to possess antiulcerogenic activity against aspirin-induced gastric ulceration in rats. It can inhibit the initiation of aspirin-induced ulcers and is also efficacious in healing these ulcers once formed. Though efficient against ulcers, its mechanism of action differs from conventional anti-ulcerative drugs like cimetidine. It stimulates the growth of the mucosa cells, upregulating mucus secretion and directly stimulating the cells to secrete mucus (Best et al. 1984). However, this vital nutraceutical property is lost during ripening and heating (Best et al. 1984).

Oxidative stress and hyperglycaemia are major metabolic changes implicated in diabetes disease. They are usually controlled with the use of antioxidants. Diabetes, along with its complications, can be controlled with plants rich in antioxidants and dietary fibre (Weickert and Pfeiffer 2008; Dhanya et al. 2015).

Several studies have reported the antidiabetic potential of unripe plantain (Ojewole and Adewunmi 2003; Eleazu et al. 2010). Plantains are employed in folklore medicine for the management of diabetes, along with liver dysfunctions, although the mechanism of action is yet to be understood.

Recent studies indicate that the consumption of unripe plantain could mitigate acute pancreatitis, and this might play a major role in the management of diabetes and related complications. As a result of this, unripe plantains potentially have the ability to contribute to the management of hepatic dysfunction, which occurs as a result of type 2 diabetes. All these roles have been adduced to the polyphenolic content of plantains (Eleazu and Okafor 2015).

Traditionally, plantain inflorescence is used in the therapy of dysentery, menorrhagia, and diabetes, as it is a rich source of phytochemicals such as dietary fibre and phenolic acids such as ferulic acid, caffeic acid, P-coumaric acid (Arun et al.

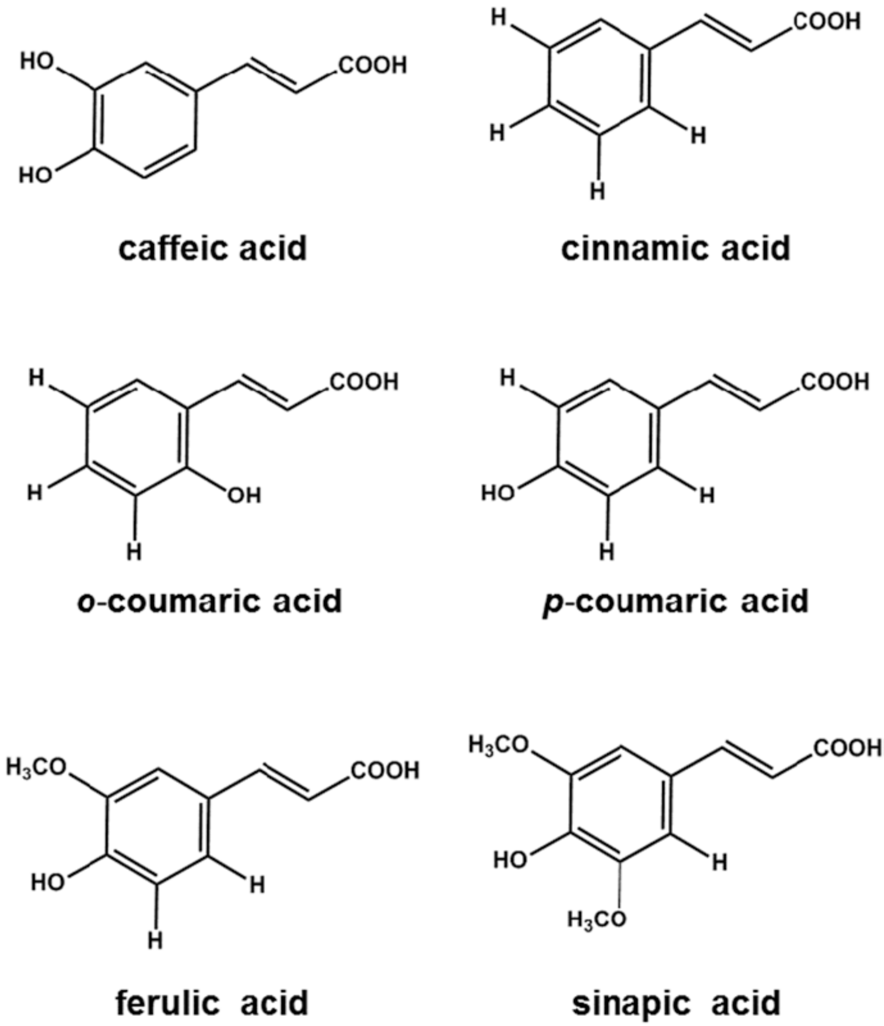


Fig. 9.3 Structures of hydroxycinnamic acid derivatives

2017) (Fig. 9.3). The mechanism by which phytochemical-rich extract of plantain inflorescence reduces postprandial hyperglycaemia is through the inhibition of digestive enzymes and enhancement of the uptake of glucose by body cells (Arun et al. 2017)

Oxidative stress plays a significant part in the onset of diabetes. The reduction in oxidative stress by methanolic extract of plantain inflorescence in an in vitro model using L6 myoblasts cell line was reported by Arun et al. (2017). The extracts were also shown to possess an antiglycation effect playing a significant role in retarding the onset of complications associated with diabetics like cardiomyopathy (Arun et al. 2017).

Green banana pulp was reported to possess protective capacities against acute (ethanol- or indomethacin-induced) and chronic (indomethacin-induced) gastric mucosal lesions in rats. This effect was adduced to more than one bioactive component of bananas (Dunjic'et al. 1993).

Consumption of green banana flour (20 g/day) for 45 days did not significantly reduce weight or bring about any changes in body composition in overweight women but decreased hip circumference and also contributed significantly to improvements in other health parameters such as a reduction in systolic blood pressure and fasting glucose (Tavares da Silva et al. 2014).

Complications arising from diabetes were shown to be prevented by the green banana pasta diet, as the liver and kidneys of diabetic rats did not exhibit protein oxidation as well as lipid oxidation in the liver. The diet reduced the production of triglycerides in the serum of the rats (da Silva et al. 2016).

These health benefits reported for bananas could also be explored for plantains as they belong to the same family. In fact, plantains could be more potent and effective than bananas in these indications.

Given these facts, more work needs to be carried out to determine the possible nutraceutical properties of plantain to fully access its benefits.

9.4 Beta Carotene and Vitamin A in Plantain

In Africa, both tropical and subtropical regions, as well as in other parts of the world, plantain constitute a major source of food and livelihood for a large number of people. Plantain is a good source of vitamin A, C, and B6 (Robinson 1996). Pro vitamin carotenoids are precursors of vitamin A and are absorbed and transformed into vitamin A in the human body (Kikafunda et al. 1996). In many underdeveloped countries within sub-Saharan Africa, (Aguayo et al. 2005). Southeast Asia and some Pacific Islands (UNICEF 1990; Setiawan et al. 2001). Vitamin A deficiency is a major health problem. Though the reports are still inconclusive, in the growing regions in Uganda, high vitamin A deficiency (VAD) rates were reported to have lasted for a decade (Kikafunda et al. 1996). About 80% of vitamin A is derived from the pro-vitamin A carotenoids present in plant foods by a majority of people in developing countries. Carotenoids are fat-soluble pigments associated with the red, orange, and yellow colours of some flowers and fruits. In inflammatory and immune disorders, cataracts and macular diseases, cardiovascular disease, neurologic as well as prevention of cancer, vitamin A possesses protective effects against these diseases' effects (Arora et al. 2008). β-carotene is an extensively studied carotenoid and the most active and predominant carotenoid in most plants and is the major precursor of Vitamin A (Kidmose et al. 2007).

Biofortification allows the accessibility of naturally fortified foods to malnourished populations in remote areas or in unaffordable and unavailable commercially marketed fortified foods (Bhaskarachary et al. 1995). Natural carotenoid-rich foods are more beneficial than synthetic β-carotene supplements since studies have demonstrated that high doses of synthetic β-carotene increase the risk of susceptibility to some diseases (Kidmose et al. 2007).

In many countries, plantain plays a major role as a staple food; thus, breeding or genetic engineering could be employed to increase its nutritional value, which should positively enhance the health and welfare of millions of people. Vitamin A deficiencies could be severed by utilising plantains for the production of weaning foods, especially in countries where diets are already plantain based. Furthermore, research has shown that plantains are a crucial source of health-promoting phytochemicals (Wang et al. 1997; Bouis 2000; Someya et al. 2002; Rabbani et al. 2004; Arora et al. 2008; Yin et al. 2008; Amorim et al. 2009; Davey et al. 2009; Setiawan et al. 2001).

9.4.1 Plantain-Rich Carotenoid: A Prospective Food Source for Relieving Vitamin A Deficiency

Plantains are rich in pro-vitamin A carotenoids, especially orange-fleshed Musa cultivars (Englberger et al. 2003; Englberger et al. 2006; McLaren and Frigg 2001). Some plantain species exposed to UV radiation showed increased carotenoid concentration (Englberger et al. 2003). Carotenoids present in plantains are in the form of α and β-carotenes (Fig. 9.4). The pro-vitamin A carotenoids present in plantains increase with the maturity of the cultivars (Englberger et al. 2003). Carotenoids are of importance in the management of various diseases such as eye diseases and cancer (Johnson 2002). Carotenes are a class of carotenoids that include β-carotenes and lycopene, which are fat-soluble. The carotenoids are responsible for the yellow colour of ripe plantains. Sun-dried, unripe plantain flour has 3.41 μg/g carotenoid content, while roasted plantain contains 12.90 μg/g and boiled plantain contains 15.10 μg/g carotenoids (Johnson 2002). Hence, domestic cooking practices appear to enhance the carotenoid content in plantains.

Vitamin A deficiency (VAD) or hypovitaminosis A has been implicated as a major problem amid global health challenges (UNICEF 1990), owing to its link to increased mortality among children and women, mainly in low-income countries (McLaren and Frigg 2001). Lack of vitamin A in the diet results in VAD. Foods rich

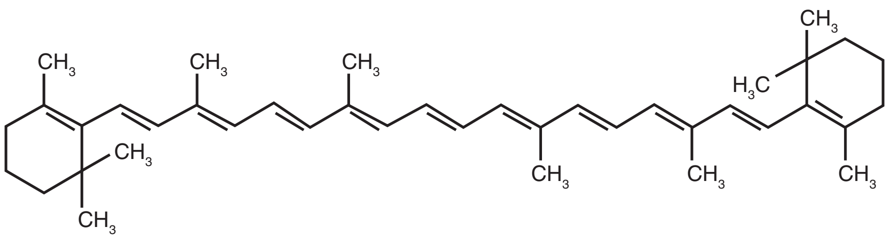


Fig. 9.4 The structure of β-carotene

in vitamin A comprise foods from animals and plants containing pro-vitamin A carotenoids, such as β-carotene, the carotenoid which contributes most to vitamin A status (McLaren and Frigg 2001). Earlier food-based methods for limiting Vitamin A deficiency, which include nutrition education and horticultural programs, have been directed to the production and promotion of vitamin A-rich foods, comprising green leafy vegetables, eggs; liver; milk; orange and yellow fruits and vegetables such as, pumpkin, carrot, papaya, orange β-fleshed sweet potatoes, mango, squash, and red palm oil as well as plantain (Ayalew et al. 1999; de Pee et al. 1998; Hagenimana and Low 2000). The vulnerability of children and women to Vitamin A–deficiency could be alleviated by increasing consumption of carotenoid-rich plantains.

In an attempt to increase the Vitamin A status in these regions, there must be a change from low β-carotenoid to high β-carotenoid plantain cultivars, resulting in an increase in diet Vitamin A content (Fig. 9.3). According to McLaren and Frigg (2001), investigation of the staple food eaten is important for accepting the cause of Vitamin A deficiency because regions where rice is consumed more are likely to have Vitamin A deficiency disorders (Englberger et al. 2003). Bouis and Hunt (1999) maintained that the approach of improving the Vitamin and mineral content of basic foods have positive returns. Studies are also being done on plant-breeding approaches to escalate the nutrient density of β-carotene, iron, and zinc in rice, wheat, maize, cassava, and the common bean (Bouis 2000). Genetically modified rice, commonly referred to as golden rice, has increased β-carotene content due to genetic modification. Non-modified rice normally contains no pro-vitamin A carotenoids and is the basic food eaten by most societies that have shown the worst Vitamin A deficiency. Therefore, the inclusion of products developed from plantains in the daily diets of these populations will boost Vitamin A intake.

9.5 The Need to Develop Functional Foods from Plantain

Food is any substance that we eat or drink that gives nutrition to sustain growth and life (Joy et al. 2016). The term functional food first originated in Japan in the mid-1980s (Wlodzimierz et al. 2005). Food could be referred to as "functional" if it possesses health-promoting effects outside its nutrition contents. Thus, improving health and well-being or lessening the risk of diseases (Gibson et al. 2000). Hence, food items with relevant functional ingredients could be called functional foods. Plantains as functional foods contain kaempferol, quercetin, myricetin, isorhamnetin, leucocyanidin, apigenin, luteolin, p-hydroxybenzoic acid, caffeic acid, glycitin, oleoresins, shogaol, gingerol, and astilbin (Kathleen 1999; Ottaway 2008). These functional compounds possess antihypertensive effects, atherosclerosis, dyslipidaemia, antihyperglycaemic, chemoprotective function in oral cancer, anti-inflammatory protection against ulcer, obesity control, diabetes, and complications alleviation (Ottaway 2008; Watson and Preedy 2010).

Functional foods could be classified as conventional foods, modified foods, and medical foods (Younes and Honma 2011). In food production, plantain plays a major role as a perennial crop with a short gestation period (Rai et al. 2009). Plantain is a foremost source of carbohydrate for above 50 million people. In Nigeria, every stage of the fruit, which is from immature to overripe, are considered a source of food. The immature fruits could be peeled, sliced, dried, made into powder and eaten as 'plantain *fufu*'. Various foods are made from mature fruits, whether ripe or unripe, which includes steamed, pounded, baked, boiled, roasted, or sliced and fried into chips. Overripe plantains are processed into beer or spiced with chilli pepper, fried with palm oil and served as snacks ('*dodo-ikire*'). In some parts of the world, the use of plantain pulp in industrial baby food production ('*Babena*' and '*Soyamusa*'), bread, biscuit, and others have begun (Rai et al. 2009).

9.5.1 Vital Functional Ingredients in Plantain

Plantain is extremely low in protein and fat, but high in starch and fibre. Plantain is rich in vitamin A, B6, and C. It helps to maintain vision, good skin, and builds immunity against diseases. When cooked green, it contains a high amount of potassium, magnesium, and phosphate. Consumption of unripe plantain products could inhibit, or inhibit the generation of free radicals, thus enabling the human system free from the buildup of radicals (Shodehinde and Oboh 2013). Industrially, high potassium content makes plantain peels valuable materials for the treatment of acidic soil and for producing soap indigenously. Plantain plays a role in the prevention and treatment of hypokalaemia. Ripening of plantain accounts for decreased phosphorus content while magnesium from peels of plantain increases as the fruit ripens. Certain amino acids present in plantain peels include threonine, valine, and phenylamine. It is also rich in α-linoleic acid, while high sugar contents of ripe plantains are quite advantageous in the production of plantain biscuits (Obiageli et al. 2016). Baby food and pastries are also produced from plantain fruits as well as beer production. Green plantain and pseudostems play an essential role in paper-making alcohol and cellulose derivatives production. The high starch content of unripe plantain aids industrial application in fuel, alcohol, and sugar production (Shodehinde and Oboh 2013). In a study conducted on *M. paradisiaca* peel extract, it was observed that the extract inhibited cholesterol crystallisation in vitro, inhibited atherosclerotic plaque and gallstones formation in vivo (Joy et al. 2016).

9.5.1.1 Antioxidant Compounds in Plantain

Antioxidants are biological substances that could be in low concentrations compared to an oxidisable substrate that delays or inhibits oxidation of a substrate (Obiageli et al. 2016). Naturally occurring antioxidants are often referred to as bioactive compounds, which are of diverse structures and mainly of plants origin.

Plantain bioactive compounds include alkaloids, flavonoids, tannins, terpenoids, anthraquinone, and carotenoids (Obiageli et al. 2016), which are of great therapeutic value. The amount, availability, and distribution are being influenced by various stages of plantain development, which also, in turn, affect their therapeutic potentials (Englberger et al. 2003). These constituents control the flavour, colour, and aroma of plantain and consist of the natural defence system of plantain, ensuring protection against insects, harsh or harmful environmental stimuli and microbial attacks (Obiageli et al. 2016). These secondary metabolites are distributed in various parts of plantain, which include seeds, fruits, stems, flowers, and other peripheral surfaces of plants (Obiageli et al. 2016). The therapeutic effect of these secondary metabolites depends greatly on their antioxidant properties. The antiradical activities of plantain bioactive constituents promote and encourage their uses in the management of various degenerative and dementia challenges. Life-threatening pathologies such as cancer, ageing, liver cirrhosis, cardiovascular disorder, etc. (Obiageli et al. 2016). Other antioxidants include the following:

Phytoestrogen: Phytoestrogens are compounds naturally found in plants that contain diverse groups of non-steroidal oestrogens. They are so named because they bind to oestrogen receptors alpha and beta. They are involved in numerous processes, which include reproduction, bone metabolism, sex induction, inhibition of aromatase, etc. After binding the receptors, they activate several genetic processes as coding sequences of the DNA molecules become activated because of the signal. Therefore, phytoestrogens can perform the functions of oestrogens in the body (Anhwange et al. 2008; Xiaomin et al. 2007). Phytoestrogens excite osteoblast differentiation and escalate osteoclast apoptosis (Kathleen 1999; Ottaway 2008). These include extracts of plants and compounds, mainly isoflavones with the ability to mimic or modify endogenous oestrogens. They do this by binding to oestrogenic receptors, thereby preventing atherosclerotic cardiovascular diseases (Pan et al. 2001).

Flavonoids: Flavonoids are secondary metabolites found in plants with a polyphenolic structure (Fig. 9.5). They are especially located in fruits, vegetables, and some beverages. They possess a varied range of health profits due to antioxidative, anti-mutagenic, anti-carcinogenic effects, thus used in the pharmaceutical and cosmetic industries.

Leucocyanidin is a flavonoid compound isolated from the unripe pulp of plantain (Fig. 9.2) with antiulcerogenic effects (Lewis et al. 1999; Lewis and Shaw 2001). According to Lewis et al. (1999), a natural flavonoid from the unripe plantain (*M. sapientum* var. *paradisiaca)* pulp aids in the protection of the gastric mucosa, especially from erosions. Leucocyanidin and synthetic analogues such as tetraallyl leucocyanidin and hydroxy ethylated leucocyanidin conferred protection on the gastric mucosa in aspirin-induced erosions in rats. Thus, resulting in increased gastric mucous thickness (Lewis and Shaw 2001). Also, research has shown that plantain and banana pulp powder showed substantial antiulcerogenic activity in aspirin, indomethacin, phenylbutazone, and prednisolone-induced gastric ulcers and histamine and cysteamine-induced duodenal ulcers in guinea pigs and rats, respectively (Lewis and Shaw 2001).

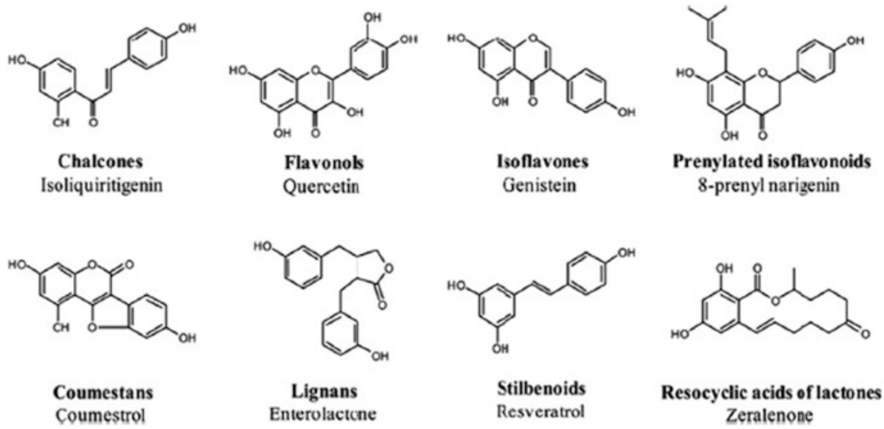


Fig. 9.5 The structures of phytoestrogen

Unripe fruit's isolated flavonoids showed hypolipidemic activity proved by a decrease in free fatty acids and phospholipid, cholesterol, and triglycerides (TG) levels in serum, kidney, brain, and liver of rats. A higher breakdown rate of cholesterol than synthesis was likened to the cholesterol-lowering effect (Joy et al. 2016).

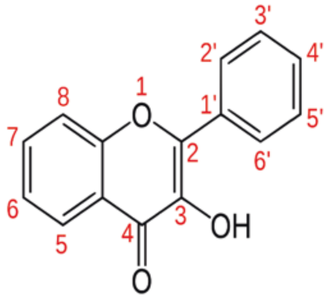
Flavonols: Some flavonoids such as quercetin and its 3-O galactoside, 3-O-glucoside, and 3-O-rhamnosyl glucoside have been isolated from the unripe pulp of plantain (Lewis et al. 1999; Lewis and Shaw 2001; Shodehinde and Oboh 2013), (Fig. 9.6).

9.5.1.2 Carbohydrates

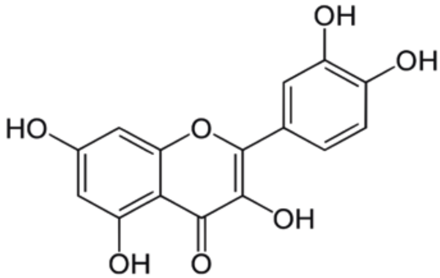
Research has shown the isolation of hemicelluloses and cellulose from various parts of *M. paradisiaca,* such as pulp and peel (Ketiku 1973). While fruit fibres from *M. paradisiaca* could lead to elevated glycogenesis in the liver, with fasting blood glucose levels lowered (Usha et al. 1984).

The unripe *M. paradisiaca* fruit hemicellulose, as well as other neutral detergent fibres (NDF), indicated low absorption of glucose and cholesterol with low serum and tissue levels of cholesterol and triglycerides (Usha et al. 1989). Total dietary fibre is abundant in Peels (Arun et al. 2015).

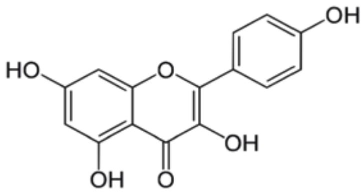
The fruit pulp of *M. paradisiaca* and *M. sapientum* are rich in starch, crystallisable and non-crystallisable sugars (Anhwange et al. 2008). Total sugar is 15%, while that of starch content of ripe fruit is 5–10% (Arun et al. 2015).



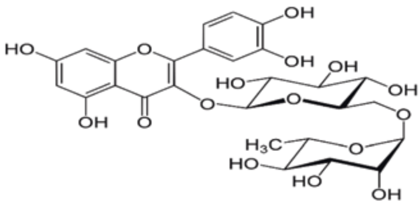
Flavonol backbone



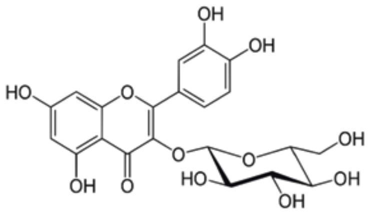
Quercetin



Kaempferol



Rutin



Isoquercetin

Fig. 9.6 Derivatives of flavonols

9.5.1.3 Vitamins

The fruit pulp of *M. paradisiaca* is rich in vitamins B and C. The plantain is also richer in ascorbic acid and carotene content than the bananas. Folic acid content has been reported as 22 µg/100 g (Arun et al. 2015).

9.5.1.4 Minerals

The green fruit of *M. paradisiaca* possesses a hypoglycaemic effect, while the fruit pulp of *M. paradisiaca* is quite rich in mineral salts (Ghani 2003). The hypoglycaemic effect could be due to stimulation of insulin production and glucose utilisation

(Ojewole and Adewunmi 2003). Both potassium and sodium high content has been linked with the glycaemic effect (Alexander 2014). Potassium content is reported as 499 mg/100 g (Arun et al. 2015).

9.6 Wastage Utilisation from Plantain

9.6.1 Plantain Peel Antioxidant Dietary Fibre for Developing Functional Cookies

Fruits and vegetable waste are underutilised and highly perishable, and seasonally posing problems to the processing industries and pollution monitoring agencies. This difficulty, however, could be resolved through the exploitation of its high-value compounds and the dietary fibre fraction, which has a great prospect in functional foods preparation. Benefits in discovering new sources of dietary fibres with particular bioactive constituents may spring up new beneficial properties to the traditionally commercialised products (Joy et al. 2016). According to this study, the idea of antioxidant dietary fibre is becoming widely accepted. Presently peels of a selection of fruits are being used as a natural source of antioxidants and dietary fibre. Based on this fact, recent reports have suggested plantain peel as an appropriate source of dietary fibre and antioxidants. In India, plantain and banana constitute the major fruit crops. India is the largest producer of plantain in the world. The considered fruit crops are among the fourth world rank of the most significant farm produces after rice, corn, and milk. Plantain compared to unripe bananas externally looks bigger with the flesh starchy rather than sweet and actually needs cooking. The peel, a major by-product of the plantain processing industry, denotes about 30% of the fruit. The environmental disadvantage of the by-product includes large quantities of nitrogen and phosphorus content and its high-water content, which makes it vulnerable to alteration by microorganisms (Joy et al. 2016). Due to consumption during various stages of maturity, the peels of plantain fruit increases with the development of processing industries that make use of green and ripe plantain. New products with standardised compositions for various industrial and domestic uses are derived from plantain peel flour (Michel et al. 2013). Several works have been carried out to explore promising value addition to plantain peel together with the production of plantain peel flour (Michel et al. 2013).

9.6.2 Bioethanol Production from Waste Ripe Plantain and Peels Using **Saccharomyces cerevisiae**

Plantain is among the principal food resources in the world. Although plantain peels contain low quantities of lignin (Rai et al. 2009), research has shown that plantain peels could be a good substrate for producing products like ethanol (Shyam et al.

2011). Environmental protection and waste management could be ensured via industrial waste food processing (Shyam et al. 2011). Natural resources and biophysical conditions have slowly turned into an economic variable. Hence, its consideration in the line of industrial performance leads to redesigning the processes of production in line with the so-called environmental technology (Shyam et al. 2011). Presently, most of the consumable fruits are highly perishable products and are lost through the Agric–food chain, owing to physiological decay, water loss, spillage, and mechanical damage for the period of harvesting, packaging, and the following years' determination have been focused concerning the exploitation of low-cost and renewable agricultural sources like discarded plantain peels as a substitute substrate for production of biofuel like ethanol (Shyam et al. 2011).

9.6.3 Exploitation of Plantain Waste in Wastewater Treatment

Pure water is a vital solvent necessary for all humans and other living things striving on planet earth, even though major populations on earth are struggling to access fresh potable water. Lack of water is a major problem in this contemporary world (DeMessie et al. 2015). In several countries of the world, groundwater is the prime source of drinkable water for their local populace in small and medium cities as well as villages. Nevertheless, the declining ground and surface water quality could be a result of the usage of fertilisers and pesticides in agricultural activities, antibiotics, dyes, and heavy metals in industrial activities (Ahmad and Danish 2017). The numerous industrial effluents uninterruptedly emptying into the river and ponds have a wide variety of pollutants that gradually enter the natural ecosystem, with significant toxic influence on human health, aquatic habitats, and plant species (Ahmad and Danish 2017).

Banana wastes were tested as adsorbents against several pollutants (Ahmad and Danish 2017). Banana wastes have gotten the attention of researchers as an effective adsorbent raw material because of abundantly available, post fruit harvesting, no proper utilisation of the banana waste by the farmers, and a significant amount of carbon compounds present in it. Furthermore, banana tree waste could be of serious environmental hazard if its waste is not efficiently managed; it could cause greenhouse effects if neglected in wet conditions (Ahmad and Danish 2017). Consequently, the choice of banana tree, plantain, and fruit waste as active adsorbent materials is quite a good choice for a viable future.

Among several wastes generated due to banana trees and fruit, the banana peel is generated in large quantities due to banana fruit consumption. Banana peel constitutes about 40% of total fresh banana fruit weight (Ogazi 1996). Banana peel comprises carbon-rich organic compounds like pectin substances, cellulose, hemicellulose, chlorophyll pigments, and some other low molecular weight compounds (Shyam et al. 2011). Banana peel has been proven to be a good source of pectin (10–21%), lignin (6–12%), cellulose (7.6–9.6%), hemicelluloses (6.4–9.4%), and galacturonic acid (Emaga et al. 2007).

9.6.4 *Plantain/Banana Waste-Derived Adsorbents Against Environmental Pollutants*

The mingling of water-soluble pollutants in aquifers due to the indiscriminate discarding of heavy metal ions has been a problem of concern worldwide. Heavy metal ions are noxious to aquatic species (flora and fauna) and human beings even at low concentrations (DeMessie et al. 2015). The heavy metal ions pollution primarily comes from iron, steel, photography, silver-plating, surface finishing industry, energy and fuel production, fertiliser and pesticide industry and application, and metallurgy (DeMessie et al. 2015). Owing to the non-biodegradable attribute of metal ions, they store and shift to a different living organism along with their food chain. Hence, their noxious properties are more revealed in animals at higher trophic levels. Metal ions are triggering serious and protracted health issues in humans. Banana and plantain wastes have been broadly explored by scientific researchers as an adsorbent against a wide range of metal ions.

DeMessie et al. (2015) likened the surface effects and adsorption capacity of the pyrolysed and dried activated banana peel with commercial activated carbon (F-400) in contrast to an aqueous solution of Cu (II) ions. Pyrolytic activation of dried banana peels gives larger mesopores (49 Å) but smaller surface area (38.49 m2/g) adsorbent with dominantly negative surface charges related to commercial activated carbon (F-400) that have smaller mesopores (30 Å) and large surface area (819 m^2/g) (Ahmad and Danish 2017). The adsorptions capacities of the commercial activated carbon (F-400) (2.39 mg/g) and prepared activated dried banana peel (38.4 mg/g) were linked and described that later have better adsorption capacity (Ahmad and Danish 2017). Although the dried banana peel has a smaller surface area, the presence of opposite charge on the surface of the adsorbent accounts for better adsorption capacity. At a lower initial concentration solution, the banana peel-derived adsorbents attained an elimination efficiency of 96%. The adsorption capacity of grounded banana peel has been found to remove lead and copper ions (Ahmad and Danish 2017). The removal of Cu (II) and Pb (II) ions were favourable at pH > 3, and the equilibrium of copper and lead adsorption was achieved within 10 min (Ahmad and Danish 2017).

9.7 Conclusion

Plantains and bananas contain interesting bioactive compounds that confer nutraceutical potentials on them, enable them as effective dietary interventions in diseased conditions, and serve as adsorbents for managing environmental waste pollutants. More research is needed with a focus on the pharmacological efficacy of plantain peels and the extraction of nutraceuticals from both peel and pulp.

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Part II
Food Security and Nutrition

Chapter 10
New Perspectives in the Utilization of African Leafy Vegetables

K. A. Taiwo and A. A. Famuwagun

10.1 Introduction

Leafy vegetables may be indigenous or traditional. Indigenous leafy vegetables are native to a particular country, while the traditional vegetables are those that were introduced to a particular country and by the farmer's selection or adoption; they have been naturalized in such a country (Van Rensburg et al. 2007). Leafy vegetables, either indigenous or traditional, are given local names in the regions where such vegetable leaf is being cultivated. With a population of over 200 million in Nigeria, about 40.1% of this populace lives in poverty as of 2020, the high number of people living below the poverty level has caused an increase in malnutrition due to consumption of foods which are deficient in nutrients such as vitamins, minerals and proteins (Udousoro and Ekanem 2013). Studies have therefore indicated that the poor nutrient intake by this large population can be addressed through the consumption of nutrient-dense leafy vegetables. These vegetables are cheap, affordable and ubiquitous and therefore can be easily accessed by the poor communities (Ilelaboye et al. 2013). Leafy vegetables have deposits of numerous useful compounds such as phenolics and phytochemicals that contribute greatly to the antioxidant properties and this provides great effects against various cardiovascular diseases and oxidative damages (Gupta et al. 2005). Access to these leafy vegetables by rural communities would also guarantee good health for the populace. Despite the rich nutrients of these vegetables, the leaves are difficult to preserve due to the high moisture content, ranging between 86% and 92%, and this may

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account for the high perishability of the leaves (Shukla et al. 2016). Extending the shelf life of the vegetables after harvest and designing efficient machinery for storage may be challenging due to this high moisture content, thus contributing to high post-harvest losses. The utilization of leafy vegetables can be enhanced, especially in the industries by extracting its active ingredients. Leafy vegetables have potentials to be used as ingredients in designing new class of food for enhanced nutrition through extraction of its active ingredients such as protein and polyphenols or using the whole leaf powders and incorporating in convenience food such as bread, confectioneries and fruit juices for the development of new classes of foods. This review therefore discusses the recent efforts aimed at diversifying the utilization of leafy vegetables in an attempt to take this nutrient dense plant resource from the plate to the industries.

10.2 Commonly Consumed Leafy Vegetables in Nigeria

Vast hectares of lands are dedicated to cultivating leafy vegetables (LV_S) in Nigeria, ranging from large farm areas to small portions of land in the backyard garden of individual houses (Gockowski et al. 2003). The three major ethnic groups in Nigeria (Yoruba, Igbo and Hausa) have leafy vegetable that are peculiar to them, such that these LVs are named based on the tribal languages (Table 10.1). Some of the leafy vegetables grown in Nigeria include wild lettuce (*Taraxacum officinale*), African Spinach *(Amaranthus hybridus),* Lagos Spinach (*Celosia argentea*), Water leaf (*Talinum Triangulare),* African eggplant leaf (*Solanum macrocarpon),* Malabar spinach (*Basella alba),* African Basil/scent leaf (*Ocimum gratissimum),* Yoruban bologi (*Crassocephalum rubens),* Fluted pumpkin leaf (*Telfairia occidentalis*)*,* Jute leaves (*Corchorus*)*, Bitter leaf (Vernonia amydgalina), Wild spinach (Gnetum africanum),* Bushbuck (*Gongronema latifolim),* Curry leaf (*Muraya koenigii),* Waterleaf (*Talium triangularea),* Rosewood leaf (*Pterocarpus mildbraedii),* Clove Basil/scent leaf (*Ocimum gratissimum)* and Moringa leaf (*Moringa olefera)*. These leafy vegetables play important roles in alleviating poverty and contribute immensely to the healthy lifestyles of the populace (Abukutsa-Onyango 2003). They are consumed in different forms, either cooked or in the fresh forms, as supporting or main dishes. The taste of some of the vegetables may be bitter, some are aromatic or tasteless (Mensah et al. 2008) and whatever taste it is, consumption of the leafy vegetables is highly valued in the Nigerian culture because of the roles they play in health's promotion and protection of Nigerians.

Table 10.1 Some green leafy vegetables cultivated in Nigeria

	English name	Botanical name	Nigerian name (tribe)
1	Wild lettuce/Dandelion greens	*Taraxacum officinale*	*Efo Yanrin (Yoruba)*
2	African Spinach	*Amaranthus hybridus*	*Efo Tete (Yoruba)*
3	Lagos Spinach	*Celosia argentea*	*Shokoyokoto (Yoruba)*
4	Water leaf	*Talinum Triangulare*	*Gbure (Yoruba)*
5	African eggplant leaf/ garden egg leaf	*Solanum macrocarpon*	*Efo Igbo (Yoruba), akwukwo Anara (Igbo), Ganyen gauta (Hausa)*
6	Malabar spinach	*Basella alba*	*Amunututu (Yoruba)*
7	African Basil/scent leaf	*Ocimum gratissimum*	*Efirin (Yoruba), Nahianwu (Igbo), Daidoya (Hausa*
8	Yoruban bologi	*Crassocephalum rubens*	*Ebolo (Yoruba)*
9	Fluted pumpkin leaf	*Telfairia occidentalis*	*Ugu (Igbo), kebewa (Hausa)*
10	Jute leaves	*Corchorus*	*Ewedu (Yoruba), ayoyo (Hausa), kerenkere (igbo)*
11	*Bitter leaf*	*Vernonia amydgalina*	*Onugbu (igbo), efo ewuro (Yoruba), shakwa shuwaka (Hausa)*
12	*Wild spinach*	*Gnetum africanum*	*Afang leaf (Ibibio), ukazi (Igbo)*
13	Bushbuck	*Gongronema latifolim*	*Utazi (igbo), arokeke (Yoruba),*
14	Curry leaf	*Muraya koenigii*	*Efirin oso (Yoruba), Marugbo sanyan (Yoruba),*
15	Waterleaf	*Talium triangularea*	*Gbure (Yoruba)*
16	Green African spinach	*Amaranthus hybridus*	*Efo tete (Yoruba), tete eleegun (Yoruba), inine (igbo),*
17	Rosewood leaf	*Pterocarpus mildbraedii*	*Oha/ora leaf (Igbo)*
18	Clove Basil/scent leaf	*Ocimum gratissimum*	*Nchuawun (Igbo) Efirin (Yoruba)*
19		*Senecio biafrae*	*Worowo (Yoruba)*
20	Moringa leaf	*Moringa olefera*	Oku-ghara-ite (Igbo) Idagbo monoyé (Yoruba)

Sources: Shirley et al. (2019); Borokini et al. (2017); Alexander (2016); Akinwunmi and Omotayo (2016); Otitoju et al. (2014); Adjatin et al. (2013); Davidson and Monulu (2018); and Uraku and Nwankwo (2015)

10.3 Some Nutrients Composition of Leafy Vegetables

10.3.1 Micronutrients in Leafy Vegetables

Human body needs both the macro- and micronutrient to function effectively. Several studies on leafy vegetables have shown they are good repositories of these nutrients (Natesh et al. 2017; Odhav et al. 2007; Shirley et al. 2019). Micronutrients comprise vitamins and minerals, which are normally required in small amounts but vital to the body, while macronutrients include fats, protein and carbohydrates, and are needed in greater amounts than micronutrients to guarantee metabolism, growth and healthy living of the body (Otitoju et al. 2014). There are increasing research evidences of high concentration of vitamins and minerals in various leafy vegetables (LV) cultivated in Nigeria. For instance, LVs such as fluted pumpkin, African eggplant leaf, moringa leaf and bushbuck are widely consumed in different parts of the country where they are found due to extensive and adequate research information on them, whereas consumption of LVs such as Yoruban bolongi, water leaf, Malabar leaf and wild lettuce are not as popular as others in areas where they are found, probably due to inadequate research and knowledge on their nutritive benefits.

Mineral nutrients are important in the body for growth, maintenance of bone health, fluid balance and are useful for several other processes. Food minerals are grouped as macromineral elements (Calcium, Phosphorous, Magnesium, Sodium, Chloride, Potassium and Sulphur) and trace elements (Iron, Manganese, Copper, Zinc, Iodine, Fluoride and Selenium). Many leafy vegetables have been shown to contain substantial amounts of minerals (Arasaretnam et al. 2018; Iheanacho and Udebuani 2009; Otitoju et al. 2014 and Shirley et al. 2019) as shown in Table 10.2. The high amounts of some of these mineral micronutrients suggest that the LVs are a potential source of nutritional intervention in Nigeria for mineral balance. The high amounts of some of the major minerals in the leafy vegetables imply that their consumption would specifically be helpful in the building of strong bone and teeth, assist in the functions of the muscles and contribute to cell membrane structures. The consumption of the leaves would also strengthen the regulation of blood pressure and the control of the reactions of the enzymes, body's fluids balance, help in the proper transmission of nerves and support the body in adequate production of haemoglobin (Nnamani et al. 2009; Adernipekun and Oyetunji 2010).

Vitamins are important for building the body's immune health, blood clotting and energy production, but these are needed in the trace amounts. Vitamins are grouped as water-soluble and fat-soluble vitamins. The water-soluble vitamins such as Vitamin B complex (Vitamins B $_{1, 2, 3, 4, 5, 6, 7, 9}$ and $_{12}$) and vitamin C (ascorbic acid) are soluble in water and not stored in the body, because they are passed out as urine when consumed in excess, as a result, the body needs a lot of them for proper functioning. Fat-soluble vitamins, including vitamins A, D, E and K, are usually soluble in fats for proper absorption and storage in the liver (Ayua and Omware 2013; Arasaretnam et al. 2017). There are substantial evidences that leafy vegetables supply reasonable amounts of the recommended daily required vitamins needed by the body per day (Natesh et al. 2017; Davidson and Monulu 2018; and Otitoju et al. 2014). Consumption of green leafy vegetables are useful for proper vision and health function, helps in immune systems and calcium absorption and bone growth, protect the cells of the body from damage, help in converting nutrient into energy and enhances the creation of neurotransmitter and collagen, the main protein in the skin (Otitoju et al. 2014).

Table 10.2 Mineral composition (mg/100 g) of some leafy vegetables

	Potassium	Sodium	Phosphorous	Zinc	Calcium	Magnesium	Copper	Iron	Manganese	References
Amaranth viridis	705	4.57	108	2.63	469	175	Trace	19.08	5.95	Shirley et al. (2019)
Amaranthus hybridus	818	Trace	61	0.99	344	166	Trace	8.87	3.66	Shirley et al. (2019)
Talinum triangulare	832	Trace	20	1.23	188	44	0.29	3.72	1.39	Shirley et al. (2019)
Solanum macrocarpon	709	Trace	64	1.01	248	75	0.43	4.39	1.36	Shirley et al. (2019)
Basella alba	7800.00	660.00	20.50	41.00	1050.00	350.00	0.10	1.40	Trace	Borokini et al. (2017)
Ocium gratissimum	2.60	3.10	Trace	2.00	1.40	17.10	8.00	3.10	4.60	Alexander (2016)
Crassocephalum rubens	4469.91	2129.04	1409		3845.88	434.13	2.6	9.6	8.22	Adjatin et al. (2013)
Telfairia occidentalis	6.43	1.53	58.34	1.02	0.96	0.74	0.14	1.77	0.56	Otitoju et al. (2014)
Corchorus olitorius	8.96	13.43	11.54	67.54	28.05	15.23	2.46	27.25	36.55	Akinwunmi and Omotayo (2016)
Vernonia amygdalina	832	Trace	65	1.23	188	44	0.29	3.72	1.39	Shirley et al. (2019)
Gnetum africanum	181.00	17.15	29.47	0.28	34.22	12.23	36.54	1.31	Trace	Davidson and Monulu (2018)
Muraya koenigii	3.13	46.00	Trace	80.67	3.77	Trace	2.40	9.44	3.38	Uraku and Nwankwo (2015)
Amaranthus dubius	52.15	72.50	30.35	95.14	22.30	26.41	3.94	95.4	15.34	Akinwunmi and Omotayo (2016)
Pterocarpus mildbraedii	91.64	202.37	506.87	122.18	128.87	84.00		12.41	2.86	Akinyeye et al. (2010)
Amaranthus cruentus	53.16	79.50	31.36	95.15	22.31	26.42	3.95	97.22	15.35	Akinwunmi and Omotayo (2016)
Senecio biafrae	536.39	14.48	Trace	3.63	242.09	392.27	0.53	4.16	Trace	Ajiboye et al. (2013)
Moringa oleifera	1583.00	36.00	354.00	3.10	2560.00	600.00	1.90	7.30	2.10	Okerulu and Onyema (2015)

10.3.2 Macronutrients in Leafy Vegetables

Macronutrients are required by the body in large amounts. They provide the body with energy, which is measured in calories or joules. The three macronutrients found in foods are protein, fats and carbohydrates. Every part of the human body, such as the brain, require energy to function properly and therefore must be supplied in sufficient quantities. The main source of energy to the body is glucose, which is richly obtained from carbohydrates through various metabolic processes (Natesh et al. 2017). The production of glucose from carbohydrates depends on the type of carbohydrates, either simple or complex. Being a source of glucose, carbohydrates provide four kilocalories of energy per gram (4 kcal/g). Leafy vegetables are rich sources of carbohydrates, ranging between 10% and 71%, making them a good source of energy.

Protein contributes to energy supply of the body in two ways, firstly, as a source of glucose through a pseudo process called gluconeogenesis, a process by which the body obtains its glucose from a non-conventional carbohydrate source. Secondly, protein contributes its energy quota to the body though amino acids (essential or non-essential amino acids). Amino acids, which are the building blocks of protein, are abundant in leafy vegetables. Famuwagun et al. (2020a) reported that the amino acid composition of *Amaranth viridis*, *Telfairia occidentalis* and *Solanum macrocarpon* are well compared with the amino acids in the leguminous seeds. Protein, which performs other functions in the body other than energy provision, such as growth, tissue repairs and muscle mass building, produces equal amounts of calorie as carbohydrate (4 kcal/g of protein food) (Gupta and Prakash 2009).

Fats enhance various functions in the body such as energy storage, organs cushioning, production of certain hormones, absorption of fat-soluble vitamins and maintaining the integrity of the cell membrane (Adernipekun and Oyetunji 2010). Three types of fats have been identified in food, and these include trans-fat, saturated and unsaturated fats. While it is advisable to avoid trans-fat, saturated fats increase the cholesterol level of the body and hence could increase the chance of having heart diseases; unsaturated fat is a good fat and usually obtained from plant sources. Fats supply the highest amount of energy to the body by contributing nine kilocalories of energy per gram of fatty food consumed (9 kcal/g). Due to the provision of the highest quantities of energy to the body, fats have been given a bad reputation. However, selecting a good fat such as unsaturated fats are beneficial to a healthy lifestyle (Otitoju et al. 2014; Ajiboye et al. 2013; Alagbe JO 2013). Fat content of leafy vegetables is usually determined using a Soxhlet extraction apparatus, although it is difficult to estimate using the apparatus, because of the chemical bond that exists between the lipids and chlorophyll in the leaves (Famuwagun et al. 2020a). Determining the fatty acids using gas chromatography may be a better representative of the fats in the leaves. Another type of fat that is found in leafy vegetables is the Omega-3-fatty acids. This fat has been suggested to play important roles in body growth and in the prevention of various cardiovascular diseases (Hamazaki and Okuyama 2001). The presence of this fat (Omega-3-fatty acids) has been reported in some leafy vegetables grown in other parts of the African continent, such as α-linolenic acid with 4 mg/g fresh weight (Simopoulos 2002). The same study also reported the presence of α-linolenic acid in some leafy vegetables such as 1.7 mg/g in spinach, 1.1 mg/g in mustard greens, 0.7 mg/g in red leaf lettuce and 0.6 mg/g in butter crunch lettuce, but omega 3-fatty acids have not been widely reported in most of the leafy vegetables grown in Nigeria.

10.4 Utilization Potentials of Leafy Vegetables in the Development of a New Class of Food

Leafy vegetables have many potentials in the development of a new class of foods, either as functional ingredients, nutraceutical in the fortification and enrichment of other food commodity. Each of these forms of usage comes with its peculiar challenges, prices and advantages. As shown in Fig. 10.1, four different by-products may be obtained from leafy vegetables, which are useful in the enrichment of other food commodities. This section examines the different ways leafy vegetables may be utilized in addition to the conventional uses.

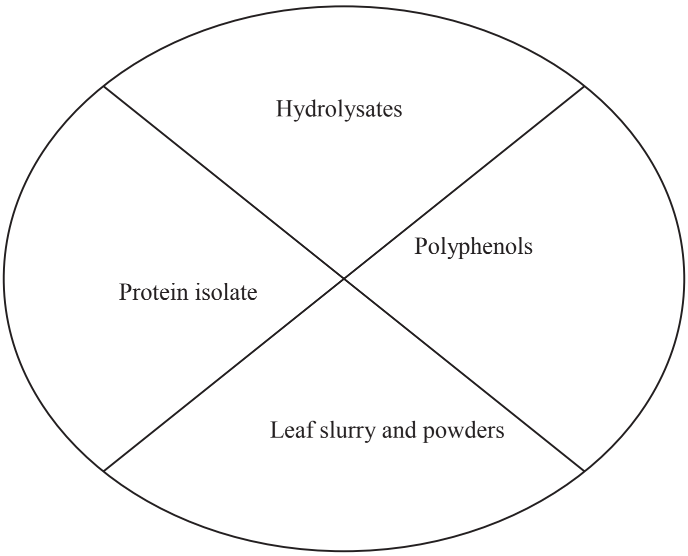


Fig. 10.1 Possible by-products from African leafy vegetable

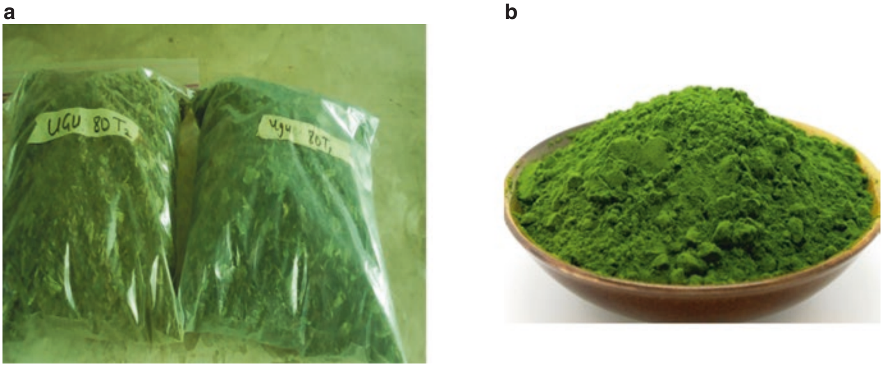
10.4.1 The Use as Part or Major Soup Ingredients

The vast nutrient in leafy vegetables has increased their utilization potentials in recent times. Leafy vegetables may be consumed fresh in salads, food dressings or as flavouring ingredients (Souzan et al. 2007). In many parts of Africa, LVs are also used as a side dish to accompany a thick starchy gruel that is the primary carbohydrate source. However, the most popular form of consumption is in their use as sources of fibre, minerals and vitamins in various home dishes (Nnamezie et al. 2019). In this case, the leaves are steamed. The leaves, after washing with clean water, are sliced and are immersed in boiled water and steamed for a few minutes before their use in soup preparations. It is important to limit the amount of time the leaves spend in the boiled water, to limit leaching of vital nutrients in the water (Nnamezie et al. 2019). In another technique, the leaves are washed and sliced into pieces; they are then poured in the already prepared sauce to cook them for some minutes. An attempt to widen the utilization potential of these leaves have recently resulted in their use as nutrient-enriching ingredients. This is to ensure that the leafy vegetables can be consumed without necessarily being accompanied by any sauce. The use of fresh and dried leafy vegetables has recently been piloted to enrich the nutrient content of local weaning and other convenient foods (Odunlade et al. 2017; Odunlade et al. 2019).

10.4.2 The Leafy Vegetable Slurry and Powders

Leafy vegetables are recognized as the cheapest and most abundant sources of carotenoids, antioxidant compounds, vitamins, pigments and minerals (Souzan et al. 2007). The technology involved in the preparation of leaf slurry and powder is very simple and can be adaptable. The leaves are washed with clean water and then blended with small amounts of water. Water is needed in the operation to ensure smooth and easy blending of the leaves to produce the slurries as shown in Plate 10.1 (Famuwagun et al. 2019). The dried form of the leaves is produced by drying

Plate 10.1 Slurries produced from leafy vegetables



Dried leaves before milling

Powders from leafy vegetables

Plate 10.2 Different forms of leafy vegetables after drying. (**a**) Dried leaves before milling. (**b**) Powders from leafy vegetables

already washed leaves in a hot air oven at a temperature less than 60 °C until no change in the dried leaves, which are later packaged as dried leaves (Plate 10.2a) or fine milled to obtain leafy vegetable powder (Plate 10.2b). The leaf slurry and the powders can be used to enrich many food commodities that would guarantee the supply of nutrients, as though it was fresh leaves that were taken (Odunlade et al. 2019). The leaf slurry can be used to improve the nutrient content of local weaning food, popularly called *ogi*.

Ogi is a popular weaning food in some parts of Nigeria, which is obtained through the fermentation of maize or sorghum. *Ogi* serves as weaning food, convalescent food and a dietary staple for adults (Odunlade et al. 2016). *Ogi* has a characteristically white to creamy colour. The colour of *ogi* depends on the colour of the raw material. *Ogi* is starchy food and therefore does not possess enough nutrient for normal body growth (Abioye and Aka 2015). Attempts have been made by several researchers to improve the nutrient base of *ogi*, one of such is the use of leafy vegetable. Odunlade et al. (2019) successfully supplemented maize *ogi* with fluted pumpkin leaf slurry (Plate 10.3). The picture showed different maize *ogi* with different colours because of addition of different percentages of vegetable leaf slurry compared with the sample without leaf slurry. The study found improvement in the nutritional qualities of the resulting ogi, such as mineral composition and antioxidant properties. The outcome of the research showed that traditional weaning foods, such as the maize/sorghum *ogi*, *are* one of the food vehicles that could be used to deliver the vast nutritional components of leafy vegetables to the target organs in the body. Apart from physically adding the slurry to *ogi*, other strategies that could be used to enrich the weaning food with fresh leafy vegetables include co-fermentation process, in which case the leafy vegetable is fermented together with the grains during the preparation of the enriched *ogi*. Another method is co-milling, where the leaves and the grains are milled together for the preparation of the enriched *ogi*. The leafy vegetable can also be squeezed with water and then sieved. After sieving, the

Plate 10.3 Maize ogi enriched with leafy vegetable slurry

supernatant may then be added to the already prepared *ogi* for the purpose of enrichment. In either of the enrichment processes, the quantity of water in the leaves must always be linked with the amount to be used in the preparation. This is necessary not to overshoot the total amount of water needed for the production of enriched products.

Bread and some snacks such as *chinchin* and cookies can also be used as a vehicle to deliver the packet of nutrient in the fresh leafy vegetable to the body. Bread is widely consumed in Nigeria and other parts of the world and is a staple food product in many countries, whose method of preparation has been in existence for a long time (Badifu et al. 2005). It is a product made from wheat, which is low in basic nutrient needed to support life. Famuwagun et al. (2019) documented the use of leaf slurry in the enrichment of bread and hence, as a vehicle to transport the nutrient in the vegetable. Care should also be taken while using the slurry in bread due to excess water. The water added during slurring process should be linked to the water needed for baking to avoid excess use of water in the final product. According to the reports, there were losses in the nutrient of the product when compared with the calculated nutrient of the mixed dough which was attributable to high baking temperature, yet, the residual nutrients in the final product were enough to meet the daily requirements and were higher when compared with the baked bread without leafy vegetable. In this case, the bread is being used as vehicle for delivering the nutrients in the leaves to the consumers.

The leaf powders can also be used to enrich bread as shown in Plate 10.4. While using leaf powder in bread, care should be taken because the presence of leaf powder in the bread recipe beyond the optimal level may impede on the rising ability of the dough during the baking processes. Hence, the need to optimize the quantity of

Plate 10.4 Bread enriched with leafy vegetable powder

leaf powder that would not negatively affect the physical and structural characteristics of the dough and the resultant bread. Famuwagun et al. (2016) demonstrated that the inclusion of 3.65% level of leaf powder was optimal when bread was enriched with fluted pumpkin leaf powder. Subsequently, Odunlade et al. (2017) reported greater retention of antioxidant activities and mineral contents of enriched bread when fluted pumpkin, amaranth and eggplant leafy vegetables powders were added to bread recipe by varying the quantities of the leaf powder between 1% and 3%. Plate 10.4 shows different loaves of bread with different colours, resulting from the use of different proportions of leaf powder in the bread recipe.

10.4.3 Phenolic Compounds in Leafy Vegetables

Leafy vegetables are rich sources of phenols, due to the presence of green pigment. Phenolic compounds are identified by the presence of aromatic rings with one or more hydroxyl groups. They are classified into simple phenol and polyphenols, depending on the number of phenol units (Napal et al. 2010; Kennedy and Wightman 2011). The main dietary phenolic compounds in leafy vegetables are flavonoids, phenolic acids, tannins, lignins and hydroxycinnamic acids. Flavonoids are the commonest form of phenolics occurring in the plant kingdom. The flavonoids, together with carotenoids and chlorophyll, determine the colour of plant materials, either blue, purple, yellow, orange or red colours. Flavonoids is a large family of phenols, consisting flavones, flavonols, iso-flavonols, anthocyanins, anthocyanidins, pro-anthocyanidins and catechins. It is a derivative of aromatic compound with three-ringed rings. Each of the family of flavonoids are differentiated by the kind of reactions (hydroxylation, prenylation, alkalinization and glycosylation) they undergo, which cause changes in their basic molecule (Ferreira and Pinho 2013; Rong 2010; Routray and Orsat 2012). The presence of flavonoids has been reported in some leafy vegetables grown in Nigeria, including *Ocimum gratissimum* (0.65%), *Murraya koenigii* (0.60%), *Amaranth hybridus* (0.27%) (Fagbohun et al. 2011; Uraku and Nwankwo 2015; Oulai et al. 2017) and other leafy vegetables. Phenolic acids are another class of phenolic compounds that occur in the form of esters and glycosides. It is a major class of phenolic compound occurring in plant, which is usually in the bound form. Phenolic acids have two main structures; hydroxycinnamic (ferulic, caffeic, *p*-coumaric and sinapic acids) and hydroxybenzoic acid (gallic, vanillic, syringic and protocatechuic acids), which are differentiated by the amount and the position of the hydroxyl groups on the aromatic rings (Pereira et al. 2009). There are phenolics in the cell walls of plants that is made up of lignins and hydroxycinnamic acids (Vanholme et al. 2010; Naczk and Shahidi 2004). They are very important for maintaining proper posture of plant during growth and protect plants against injuries and the actions of ultraviolet lights. Tannins (hydrolysable and condensed tannins) is another group of phenolic compounds that is present in plant kingdom (Soto-Vaca et al. 2012). Though classified as antinutrient in other plant species, its health benefits and the presence of hydroxyl groups in its molecule made to be part of phenolic compound. The hydrolysable form of tannins is easily hydrolysed with acids, alkaline and enzymes and this includes tannic acid (Giada and de Lourdes 2014). Condensed tannin or proanthocyanidins are difficult to hydrolyse with acids, alkaline and enzymes because it is chemically combined with other compounds. Examples include catechins and leucoanthocyanidin. In some cases, hydrolysable tannins share some similarities with condensed tannins in that it is may be esterified with other compounds such as gal oil, resulting in compounds of high molecular weight (Scalbert and Williamson 2000; Sánchez-Moreno et al. 2002; Hollman 2001).

10.4.3.1 Preparation of Phenolic Compound from Leafy Vegetables

Pre-preparatory processes of leaves usually precede extracting the active ingredients such as polyphenol from leafy vegetable. This step is very crucial in maintaining the integrity of the active ingredients (Famuwagun et al. 2017). The choice of sample preparation step for phenolic extraction from leafy vegetable usually depends on the type and the sample matrix, the properties of phenols, polarity, concentration and the number of hydroxyl radicals within the molecular structure of the phenolic compounds (Singh et al. 2011). The variations in the chemistry of different types of phenolic compounds in the leaves is a major factor to consider during sample pre-preparation processes. The purity of phenolic compounds to be extracted depends on the level of complexation of phenolics with other nutrients like proteins, carbohydrates and minerals within the sample matrix (Quanhong and Caili 2005). After the receipt of the leafy vegetables, the pre-sample preparation steps follow. The leaves are destalked, sorted and rinsed of dirt with water. The choice to dry or not to dry is the first step in the sample preparation procedures. If the leaves are to be dried, various drying methods, such as oven drying, sun drying, freeze-drying and air-drying may be used to reduce the moisture content of the leaves before extraction. Each of these drying methods has its peculiar effects on the content, yield and the functionality of the phenolic compounds being extracted. To maintain the integrity of the samples vis-à-vis the active ingredient, the use of freeze-drying and air-drying may be preferred (Famuwagun et al. 2017). However, freeze-drying is a capital-intensive process, while air-drying may be time-consuming. The use of a temperature-regulated oven for drying is one of the ways to reduce the time consumed during air-drying process, but the temperature of drying needs to be optimized to prevent disintegration of heat labile phenolic compounds. Usually, a drying temperature of $<60^{\circ}$ ˚C has been suggested in some studies for drying leafy vegetables. Sun drying process is less expensive and not time-consuming unlike air-drying, but the inability to control the natural drying temperature is a huge challenge for researchers, due to dynamic nature of the weather (Nnamezie et al. 2019). The dried samples are then ground finely with blender or sieved afterwards to obtain homogenous particle size leaf powder for extraction. The milled samples are then packaged in airtight containers before use. For some preparation techniques, the drying step is skipped. After the pre-preparation steps, the leaves are wet milled using laboratory mortar and pestle or grinder (Odunlade et al. 2019). In each of the methods of sample preparation (wet or dry milled), the leaf sample must be mixed with solvent to make a suspension during polyphenol extraction. Organic solvents, such as ethanol, acetone, diethyl ether or a mixture of water with these solvents, have been used (Dai and Mumper 2010). Sample to solvent ratios of 1:5, 1:10, 1:15 or 1:20 may be used at different extraction times, depending on the optimization of extraction variables. After the mixing stage, the suspension is first sieved using muslin cloth and later centrifuged to remove insoluble materials. The supernatant is then evaporated to dryness using a rotary evaporator or can be freeze-dried with a freeze dryer in case of aqueous extraction (Famuwagun et al. 2017). The dried material is referred to as crude polyphenol extract (CPE). The CPE may be further purified to different phenolic fractions, using sophisticated equipment such as high-pressure liquid chromatography (HPLC) in order to purify and separate the crude polyphenols into individual phenolic compounds. Studies have reported the bioactivities of polyphenol extracts from leafy vegetables and confirmed their potentials as functional ingredients.

The use of crude and purified phenols in the development of a new class of food may be done in two ways; first, as nutraceuticals, in which case the functional ingredient may be palleted or tableted in to shapes to tackle any perceived illness. The second way is the use in the development of functional foods. The phenols can be added to food commodity suitable to transport the ingredient unhindered to the target organ in the body. However, works still need to be done to ensure the vehicle does not interfere with the perceived bioactive properties of the phenols.

10.4.4 Protein and Peptides in Leafy Vegetables

Leafy vegetables are consumed majorly for their high concentration of phenolic acids, vitamins, especially ascorbic acid (Famuwagun et al. 2017). There is a dearth of information on the protein content vis-à-vis the peptides in the leafy vegetables, as only few publications are available in the research space. However, evidence from recent publications on leafy vegetables have shown that food proteins function as nutrients and also have physiological roles in the body (Famuwagun et al. 2020b). Peptides are small fragments of proteins, which can only be released by enzyme actions (Aluko 2015). The physiological roles of protein in the body are performed by the peptides, which are usually present within the primary protein structure. Due to the biological functions of peptides, they are called bioactive peptides. The food-derived peptides are obtained from food materials through a series of value addition processes of the crude proteins. The leafy vegetables grown in Nigeria have reasonable amounts of proteins, which can enhance their chance for peptide extraction (Famuwagun et al. 2020a). The protein is first isolated from the leafy vegetable powders or slurry in order to increase the protein content. The protein isolate is subjected to enzymatic actions to hydrolyse the protein by breaking the peptide bonds to produce hydrolysates (Girgih et al. 2011). This is called crude protein hydrolysates. The crude protein hydrolysates are then fractionated or purified into peptides of small molecular weights. However, the higher the crude proteins in the food materials, the higher the amounts of protein hydrolysates that could be obtained, though this sometimes depends on the solubility of the proteins to the actions of the enzymes (Udenigwe and Aluko 2011). The quantity of crude proteins in the fresh leafy vegetables is usually low (<5.0%), due to high moisture content, hence the need to reduce the water content of the leaves though various modes of drying techniques, in order to obtain high protein yield. Hydrolysates and resulting fractions can be used as functional ingredients in the development of functional foods or as nutraceuticals (Aluko 2007), which in turn will expand the fortunes of the leafy vegetables in the effort to take it to the industries.

10.5 Isolation of Proteins and Preparation of Hydrolysates from Leafy Vegetables

The sample preparation steps leading to the production of peptides from leafy vegetables is similar to that of polyphenols in terms of destalking, washing and drying or macerating. After this stage, the leaf powder or slurry is subjected to protein isolation process using the combined processes of solubilization, precipitation and neutralization (Ajibola et al. 2011). Prior to these steps, the dried and milled leaf powder is subjected to acetone extraction to reduce load of compounds (polyphenols) that may interfere with the smooth extraction of proteins. Since the protein and polyphenol in the leaf are chemically bonded together (Famuwagun et al. 2020a), care must be taken during the partial removal of chlorophyll from the leaf to avoid loss of proteins. In this case, a 5% suspension of leaf powder in acetone is stirred continuously for 1 h and the acetone layer is filtered using muslin cloth. For the very green leafy vegetables, the process of chlorophyll removal may be repeated for two or three times using fresh absolute acetone. The residual acetone from the depolyphenolic material is removed by spreading under a fume hood for 48 h. For some processes, the leaves are macerated without going through the drying process. In such a method, removal of polyphenol using acetone is not necessary. The leaf slurry is subjected to protein solubilization without regard for polyphenol interference in the process.

In the protein isolation process, the protein solubilization involves adjusting the pH of the suspension of the leaf powder or slurries to that point where the protein is most soluble using either 1 M NaOH or 2 M NaOH (Adebowale et al. 2009). The point at which protein is most soluble must have been pre-determined using Lowry methods of protein determination. For most leaf proteins, the point of highest protein solubility is usually between pH 9 and pH 10. These pH values are maintained for 1 h with continuous stirring. The solution is centrifuged and the residue is discarded. This process removes the insoluble carbohydrate and fibre from the leaf materials. To the supernatant, the pH is adjusted to the point at which the protein is least soluble, also called isoelectric point, whereby the positive and negative charges of the solution is zero. The isoelectric pH value of most leaf proteins is between 3.5 and 4.5. Acidic solutions, such as 1 N HCl or 2 N HCl is usually used to adjust the pH of the solution and this is called precipitation process. The pH value is maintained for another 20 min to allow the solubilized proteins to precipitate, after which the mixture is centrifuged. The supernatant is discarded while the slurry is the precipitated proteins. The significance of this stage is the removal of soluble carbohydrates and minerals. The slurry is then washed with deionized water and pH of the slurry is neutralized prior to freeze-drying to obtain the protein isolate.

Usually, the protein isolate has about >70% protein content. Hydrolysates are mixtures of oligopeptides or polypeptides that are produced using hydrolysis. Hydrolysis is the process of breaking the peptide bonds in the intact proteins either with enzymes or acids. Enzymatic hydrolysis is one of the safest methods to produce crude hydrolysates because it protects the integrity of the peptides (Aluko 2015). In this case, proteases of different grades and specificities (Pepsin, Pancreatin, Alcalase, Chymotrypsin, Trypsin, etc.) are used to break the peptide bonds in the proteins to yield hydrolysates (Udenigwe and Aluko 2011). This is because the peptides are usually present within the structure of the primary proteins. Smaller fractions of the peptides may be produced by subjecting the hydrolysate solutions to ultrafiltration membrane process of different molecular weights, such as <1 kDa, 1–3 kDa, 3–5 kDa or 5–10 kDa. These small fractions of peptides can be further purified using high pressure liquid chromatography (HPLC).

10.5.1 Application of Peptides as Functional Ingredient in Fruit Juice

Hydrolysates and the resulting fractions of some leafy vegetables, such as the fluted pumpkin, amaranth and eggplant leaves have been evaluated to exhibit various bioactivities such as antioxidant, antidiabetic and antihypertensive properties (Famuwagun et al. 2020a, b). The studies, which further produced small molecular weight peptides of different sizes (1 kDa, 1–3 kDa, 3–5 kDa, 5–10 kDa) with greater potentials to function as substances that can be used to tackle various degenerative diseases, resulting from potential effects of free radicals. The study by Graves et al. (2016) showed that active ingredients of this nature can be used as nutritional interventions for various illnesses ravaging the world either through their use as nutraceuticals, in which case they are tableted or as functional ingredients that require the use of food vehicles to transport the peptides to the target organs in the body. Another work by Famuwagun et al. (2019) evaluated the stability of <1 kDa peptide size obtained from three different leafy vegetables in orange juice. The strategies for its use involved the addition of the freeze-dried peptides (after evaluating them for bioactivities) to the fruit juice using the calculated effective or inhibitory concentrations that scavenged/chelated 50% of the radicals (EC50) or inhibited 50% of the Alpha amylase and glucosidase enzymes (IC50). The added peptides were mixed thoroughly with the juice and evaluated for various bioactive properties. The results from the study showed that leaf peptides were stable for about 10 weeks, suggesting that the peptides are good candidates of functional ingredients and fruit juice could be used as a veritable vehicle to deliver bioactive properties of the ingredients to the body.

10.6 Challenges in the Use of Leafy Vegetables or Their By-Products

The interest of the final consumer (s) regarding any new class of food is of paramount importance when such food is being developed. Consumers may shy away from buying any new class of food if such food does not in any way resemble any conventional brand, irrespective of the nutritional constituents. This aspect of marketing poses a great challenge to the manufacturers in a bid to develop a new class of food containing any functional ingredient.

Colour is one of the most important sensory characteristics that influences the decision of a consumer to purchase food commodity. The consumer expects that the colour of a new class of food should not be totally different from the existing ones, to create rooms for comparison. Irrespective of the nutritional constituent of new a class of food, the colour of such food commodity need to be attractive. Leafy vegetables are green in colour, and this is a great challenge for its use for nutrient enrichment. Apart from the form of use of the leaves or its by-products in the preparation of dishes or as part of ingredients in soup preparations, every other product where leafy vegetable is used for enrichment has colour challenge. The use of leaf powder in enriching bread and cookies appeared to be green unless little quantity is used. The study by Odunlade et al. (2017) explained that despite the high nutrient content of bread fortified with 3% vegetable leaf powder, some consumers scored the product very low during the sensory evaluation. Although, the use of lower percentage, such as 1% level of inclusion improved the nutritional status of the enriched bread, this was significantly lower ($p < 0.05$) when compared with that of 3%.

Leafy vegetable has high moisture content of about 80–94%, hence the leaves cannot be preserved for a long time in its fresh form (Hossain et al. 2017). Drying of the leaves is one of the most effective ways of preservation, though in its dry form. Drying leads to loss of nutrients because most of the active ingredients in the leafy vegetables are heat labile (Nnamezie et al. 2019). For instance, there is considerable amount of loss in the vitamin C and mineral contents of fluted pumpkin leaves when dried at 60 °C (Nnamezie et al. 2019). However, drying of some leafy vegetables, such as fluted pumpkin, amaranth and eggplant leaves increased the protein content of the leaves from <5.0% to about 20–35% (Famuwagun 2019). Therefore, the fear of nutrient loss during drying is one of the challenges faced in a bid to use leaf vegetables/their by-products in the development of new class of food.

10.7 Recommendation on the Use of Leafy Vegetables and Their By-Products

The use of leafy vegetables in the enrichment process will, in no small measure, increase utilization potentials of the leaves, which will further enhance productivity. Not only will it improve the utilization but also reduce the colossal post-harvest losses that are usually being experienced during production glut. Although the use of leafy vegetables in the development of new class of food comes with many challenges, especially with the colour and loss of nutrients during drying, the immense benefits should be considered while making the decisions. The consumers of the new class of food should be aware that, most of the time, development of nutritious or medicinal food commodity may affect one or more of the sensory attributes. For instance, in the production of enriched bread and cookies, product that contained higher level of vegetable leaf inclusion resulted in darker or greener appearance, though most nutritious. It is therefore important for consumers to make a choice between healthy living and sensory pleasures. The manufacturers or the producers of the new class of food also need to consider the fact that it is only what the consumer sees good in their sight that can go through the mouth, regardless of how nutritious such food commodity is. Hence, the need to maintain a balance between what the manufacturer wants and the choice of the consumers.

The manufacturers of the new class of food containing leafy vegetable may also need to optimize the level of inclusion of the vegetable leaf by-products in the enriched food commodity, using the sensory characteristics as responses. By doing this, the manufacturer of the new class of food may be able to clear the doubts of the consumers and produce that class of food that will satisfy the sensory and the nutrition needs of the consumers.

Producing a purer form of the active ingredients in the leafy vegetable may also be a way out to satisfy the need of the consumers. For instance, the vegetable leaf powder is usually green in colour. When the protein is isolated, especially the fluted pumpkin, amaranth and eggplant leafy vegetables, with about 95–98% protein content (Famuwagun et al. 2020a), the colours of the proteins are dark (Plate 10.5), which may not still be attractive to some consumers. When the proteins are hydrolysed using proteolytic enzymes, the colour of the hydrolysates are either chocolate

Plate 10.5 Protein isolates from leafy vegetables

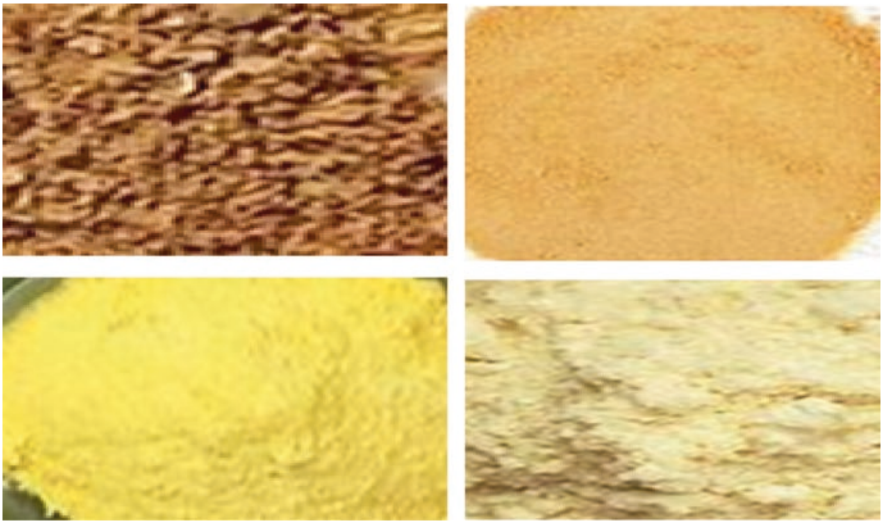


Plate 10.6 Protein hydrolysates obtained by enzymatic hydrolysis by different proteases

in colour or creamy, depending on the enzyme used for the hydrolysis (Plate 10.6). The hydrolysates when used in the enrichment process will result in a new class of food with acceptable colour and this will satisfy both the sensory and the nutrition needs of the consumers. Apart from proteins, polyphenol is another active ingredient that can be purified in leafy vegetables. When the crude polyphenol is obtained from the leaf powder, the colour is usually either green or dark, depending on the type of vegetable. Purifying the crude polyphenol into different phenolic fractions removes the dark or green colour to produce brown colour, which can be used in enrichment process to produce an acceptable functional food.

10.8 Conclusion

Leafy vegetables are a green area of research that has not been well tapped by both the researchers and the manufacturers. Despite the numerous leafy vegetables on the African continent, it is still surprising that the crops have not moved beyond the *pots.* This chapter has discussed the various by-products from the leafy vegetables that can be used to produce a new class of food as well as possible food commodity that can serve as vehicles to transport the nutrients in these by-products to the target organs in the body. However, either most of the leaves are seasonal crops, which are mostly available during the rainy season, transforming the leafy vegetables into another form, through drying or production of functional ingredients, will still afford the consumers to enjoy the benefits of the leaves when not in season. It is therefore important for researchers and manufacturers to work together and make leafy vegetable the economic crop that it truly is.

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Chapter 11
The Uptake of Farming Technological Innovations for Food Security in Kejom Ketinguh in the North-West Region of Cameroon: A Contribution to Anthropology of Food Production

Monju Calasanctius Matsiale

11.1 Introduction

The welfare of most rural populations in the world depends directly on farming to produce food crops for consumption. Food production is not a recent development. Early humans started producing food between 12,000 and 10,000 years ago, following innovations in plant and animal domestication (Melinda, 2011). Food production was intended to satisfy the rapid population growth that early humans witnessed. Until then, man had largely depended on hunting and gathering as the principal means of getting food to sustain life (Svizzero et al., 2014). It required a lot of energy and time for man to acquire food since he had to wander from place to place. Such wandering was complicated by the variation in the availability of animals for hunting and plants for gathering.

The efforts, energy and time man spent acquiring food exhibit the importance of food. Food is taken not only for growth but also as a means of replenishing lost material from the body. Abeh (2003) wrote, 'the lack of food or insufficient food intake can impact enormous consequences to individuals such as low faculty development, low productivity, poor health morbidity and eventually mortality…' From the above quotation, one can conclude that food is one of the key basic needs to all humans, especially as far as health is concerned.

The international body has understood the basic role food plays in reconstructing human health and is therefore seeking ways to make food available and accessible to all at any time. In order to do this, World Health Organisation (WHO) under the watchful eyes of the UNO, organised a worldwide conference with importance attributed to Primary Health Care (PHC) in Alma-Ata, former Union of Social Socialist Republic (USSR) in 1978. In this conference, it was emphasised that food

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plays an important role in stabilising human health and hence set a target for the year 2000 to achieve global health by increasing food production and supply. In Article 7, Sections 3 and 4, the promotion of food supply, nutrition and agriculture were recommended as part of the solution in solving the prevailing food scarcity.

The perennial problems of food shortages continued after the year 2000 and the international body, under the auspices of UNO in the year 2000, reviewed the targets set in Alma-Ata in the widely known goals referred to as the Millennium Development Goals (MDG). There are eight goals in number aimed at curbing the problems hindering the progress of humans at all levels. This chapter is in line with goal one, target two, which stipulated that the increase and availability of food through food production at all levels should be set as a target in the years ahead. In fact, this goal estimates that 'the proportion of people who suffer from hunger shall be cut by halve between 1990 and 2015'. This goal came within the backdrop of numerous problems affecting world food production systems.

Nowadays, one of the most crucial challenges to society is overseeing that production of food should be sustained in a manner that food security can be ensured. Actually, people cannot survive without food. In fact, after water, food is the second concern of humankind. As a consequence, the question where and how to get food has pushed humanity to search for means for its procurement. The need for food has led to the development of systems of farming that have consumed land and water. Worsened by rapid global population explosion, farmlands have been reduced by human settlements, thereby jeopardising the very systems of farming that are out to ensure food security.

According to the World Bank (1982), 'agricultural production growth rate in sub-Saharan Africa has declined over the years since the 1970s. Food production declined steadily from an annual average of 2.6% in the 1960s to 1.6% in the 1970s and then to 0.9% in the 1980s'.

Olayemi (1996) observes that 'a combined effect of declining food production and increasing population resulted in the increase in the importation of food to West Africa at an annual rate of 9.7% during the period 1986 to 1992'. The Secretary General of the United Nations Organisation (UNO) was quick to remark that…'the world's food systems are in crises. They are dysfunctional and are failing too many people and many of our most vulnerable nations...' (Ban Ki-Moon, 2009).

Basing our thinking on the statistics presented above, one is forced to argue that it was necessary for the international body to revisit the targets set up in Alma-Ata in 1978. This is to ensure that food production systems are managed in a manner that food security can be continuous to make available and accessible foods at all times and at all levels to humans.

Most countries south of the Sahara, which were signatories at the Millennium Development Goal Conference, were called upon to set up strategies to reduce hunger by taking up farming technological innovations that could increase food production and ensure food security. According to Prowse & Braunholtz-Speight (2007), 'over 60% of people in sub-Saharan Africa are reliant on Agriculture'. Thus, uptaking of farming technological innovation is of utmost importance to ensure that food production is increased and maintained in order to guarantee food security.

Plagued by economic crises since the late 1980s, Cameroon was forced to neglect agriculture. Seemingly, this neglect is gradually turning grounds because farming technological innovations through government-specialised agencies like IRAD and IRZ are being introduced to ensure that there is abundant food production. The civil society has equally stepped in to promote food production, especially at the local levels. Going down memory lane, the importance of food production to the general welfare of the people of Cameroon was recognised even before independence. Few years after Cameroon gained autonomy from France and Britain, the government under President Ahidjo was determined to increase productivity in agriculture by paying attention to food production under the famous five-year development plans. The first segment of the five-year plan, which fell between 1963 and 1967, was referred to as 'the farmer's year' while the second segment (1967–1971) was doped 'the farmer's plan'. Fonjong (2004) significantly explains this approach. Again, the agricultural show schemes and best farm competitions served as additional incentives to farmers to boost food production, hence ensuring food security. However, this attention on food production did not last for long. 'There was a systematic neglect of the agricultural sector and its infrastructure. Major funding schemes like FONADER and agricultural institutions like MIDENO were either closed down or tactically abandoned' (Fonjong, 2004).

The inception of new global economic order known as globalisation, urged Cameroon to involve the civil society as partners in handling issues that could enhance the progress of the local population, be it in the domain of health, agriculture or educational innovations. In addition, in order to further implement the Millennium Development Goals (MDG) on the field, the state developed the Poverty Reduction Strategy Paper (2010) in Cameroon, which realised the gross inequality in the supply of food and proper nutrition to the people, particularly between urban and rural areas. As such, it observes 'The promotion of food production and then supply, if based on international order, is of basic importance to the fullest attainment of health for all in Cameroon'. It therefore puts considerable emphasis on agricultural diversification and productivity in particular to achieve food security and hence stabilise health. The boosting of food production through innovations is placed as a primordial issue in this paper, considering the fact that agriculture employs more than 60% of the Cameroonian population (Fonjong, 2004).

Almost all the divisions that make up the North-West Region have benefited from government intervention in the domain of farming through agencies such as MIDENO, WADA, IRZ and PAFSAT. Despite the partial closure of some agencies like WADA, international as well as national agricultural NGOs have made efforts to introduce farming technological innovations to improve food production in the different villages of the six divisions found in the Region. *Kejom Ketinguh,* which has been chosen as our study area, is not left out in the search for improving food production through farming technological innovations.

Each agrarian society has its unique farming system that is determined by culture, environment and climatic factors. *Kejom Ketinguh* as a society is not different; they had depended on their traditional farming systems for decades. The population explosion in recent years meant that they had more mouths to nourish; traditional farming systems have been proven ineffective to ensure continuous food production hence guarantee food security. It is against this backdrop that up-taking farming technological innovations became the only way out to help boost food production in the locality and beyond. The main objective of this chapter therefore is to examine the farming technological innovations that had been introduced in *Kejom Ketinguh* as a solution to the decline in food production through the traditional farming systems.

11.2 Brief History and Location of Study Area

Data for this chapter are excerpts from my master's thesis dissertation, collected in Kejom Ketinguh between 2011 and 2012. Thus, the following paragraphs will present a brief history and location of the study area.

11.2.1 Brief History

Narratives from discussions with some custodians of culture hold that the people of *Kejom* in the North-West Region of Cameroon originated from the North-East of Africa. They started their migration by passing through the Lake Chad basin and then travelled southwards towards the present Adamawa region. From there, they travelled and fought many wars along their way before settling in *Kefem* near the Kom Fondom. Presently, they occupy two villages, (*Kejom Keku*, *Kejom Ketinguh*) in the Tubah subdivision. They shared the same history up to the first half of the nineteenth century when they separated because of diversified views over the celebration of the annual dance. As explained by Mundi (1990):

> In Kejom, the annual dance is a very special ceremony that is hosted by the Fon to commemorate the death of all princes. It is intended as a special celebration of the death of Fon Mbwuwain or Mbwungang, who died without leaving a child to succeed him. It is also a period of prayer for food production for the forthcoming season. During this dance, many initiations are carried out in the village if there is a death in the palace, the dance cannot take place. It so happened that during the period of the dance, a prince died. The name of this prince was Ninying. Should the dance continue in keeping with the customs – since the dance had already been announced by the Kwifon and was in progress? To respect the customs, the dance continued. Quite dissatisfied, seventeen princes and their families decided to migrate from Kejom to form the present-day Kejom Ketinguh.

The quotation above brings out the reason for which two *Kejom* villages exist in the Tubah subdivision. It equally provides us with the origin of the *Kejom Ketinguh* people. Mundi finally concludes 'the split was caused by a family quarrel which eventually involved the entire *Kejom* people and which occurred during the period of the annual dance'. He terms it 'family quarrel' because it occurred between princes who were descendants of the *Fon's* Family line.

Table 11.1 The *Fons* that have reigned in *Kejom Ketinguh*

Names of *Fons*	Estimated year of birth	Period of reign
Aseh I	1796	1845–1881
Phuanchu	1841	1881–1919
Anguh	1869	1919–1934
Aseh II	1896	1934–1960
Shiteh II	1945	1960–1981
Vuyugho	1963	1981–

Adapted from Mundi (1990)

Though the princes and families separated with ease, their movement to the present site (*Kejom Ketinguh*) was not easy. This was because they had to use their small population to fight already established villages. These villages were *Balikumbat*, *Babessi* and *Bamessing*. In the face of hostilities, they appealed to their brothers they had left behind to assist them fight their enemies. This was done most often, the *Kejom Ketinguh* people won. After chasing away their so-called enemies, the 17 princes and their families finally settled on their present site. In order to establish an autonomous village, they first named the village *Kejom Ketinguh*, meaning '*Kejom* under the rocks or under the stones' to differentiate it from *Kejom Keku* which is '*Kejom* in the forest'. Perhaps this name was inspired by the fact that they settled between three large stones, which are common geographical features in the village. Second, they made one of their brothers a *Fon*. Aseh I, as he was called, became the first *Fon*. Since then, the *Kejom Ketinguh* people can boast of six *Fons* who have been enthroned. Table 11.1 presents the Fons who have ruled Kejom Ketinguh from 1845 to the present.

The *Kejom Ketinguh* people share every cultural element with the people of *Kejom Keku* – language, social organisation and political organisation. The two *Fons* sit side by side during cultural manifestations in their respective villages.

11.2.2 Location

Kejom Ketinguh is located in the Tubah subdivision, alongside other villages. The surface area of Kejom Ketinguh is about 108 km^2 (Ngwe 2007). The village shares common boundaries with *Bamessing, Balikumbat, Kejom Keku* and Kom and *Bambili*, respectively. The distance between the village and Bamenda (Regional Headquarters of the North-West Region) is 27 km. along *Bamenda/Ndop* highway. The population is labour force par excellence as far as farming is concerned. Though most of the youths have left the village for greener pastures in the big cities, a reasonable number still remain. Figure 11.1 shows the different villages that share boundaries with Kejom Ketinguh.

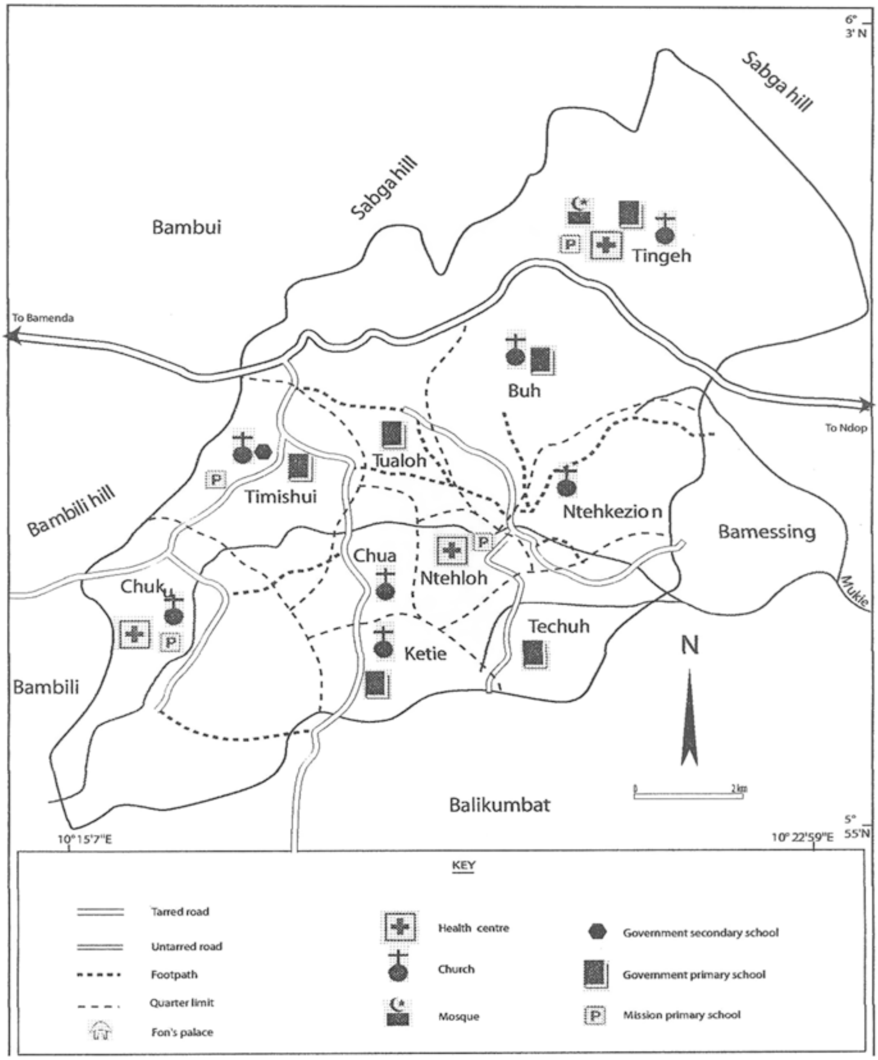

Fig. 11.1 Map showing Kejom Ketinguh and its neighbouring villages. (Source: Adapted from the 1992 administrative map of Cameroon)

11.3 The Perception of Farming Technological Innovations

Farming technological innovations are the new ideas or practices that have been introduced to farmers in *Kejom Ketinguh* with the aim of ensuring food security (Mbongsi, 2011). These changes are not new to farming vocabulary but are quite new to the *Kejom Ketinguh* people. That is why, during fieldwork, we tried to find out what they understood by farming technological innovations and their perception of them.

Many farmers understood what farming technological innovation meant but bringing out a clear definition was difficult. However, they brought out their perception on these new changes. Their perception ranged from positive to negative aspects. Others, especially the younger farmers, viewed it as a way of improving farming knowledge and techniques of farming, while others were of the opinion that it is out to provide farmers with money and improved seedlings to help them increase their harvest (Jayashree et al., 2008). The older generation of farmers on their part, saw the farming technological innovations as a way of enriching some people through the sufferings of poor farmers, while others identified the food products of farming technological innovation as tasteless.

The reaction of the older generation of cultivators is justified by their deep-rooted attachment to their traditional way of farming. Turning away from traditional practices and adopting new ways becomes very tedious (Hume 2006). Consequently, rejecting them becomes the only way out. The people's perception explains why most people in Cameroon are embracing farming technological innovation reluctantly.

11.4 The Farm

Generally, food production is carried on a farm; the farm is a platform where crops are cultivated and animals are reared. The Kejom Ketinguh people as a piece of plot where they work and cultivate food know the farm. Others perceive the farm as a place where they go almost on a daily basis to work. The peoples' knowledge about the farm enables us to understand how it is perceived within the framework of technological innovations. The farm is seen within the scope of farming technological innovations as a system. Thus, the farm as a system can be viewed from the angle that it is made up of different related elements. These elements work together for the farm to function well in producing the foods needed by the people of the village under study. According to Ruthenberg (1976)

> farm as a system consisted of a set of related sub-systems which form a hierarchy of farms: micro-organisms in the soil […], crop-producing system" He continued by saying that "some of the subsystems involved are 'machine' system (tractors) and other biological systems (plant, soils, animals), while the workers belong to social systems. (Ruthenberg, 1976)

While Woermann (1959) cited by Ruthenberg (1976) observes 'a farm is taken to be an organised economic unit in which crops and livestock production is carried out with the purpose of producing an economic net return'. Thus, a farm is organised to achieve the immediate objectives of the farmer who is the manager. In our case study, most farmers are smallholders, working primarily for consumption, while the little surplus left are sold to enable them to purchase some other household needs.

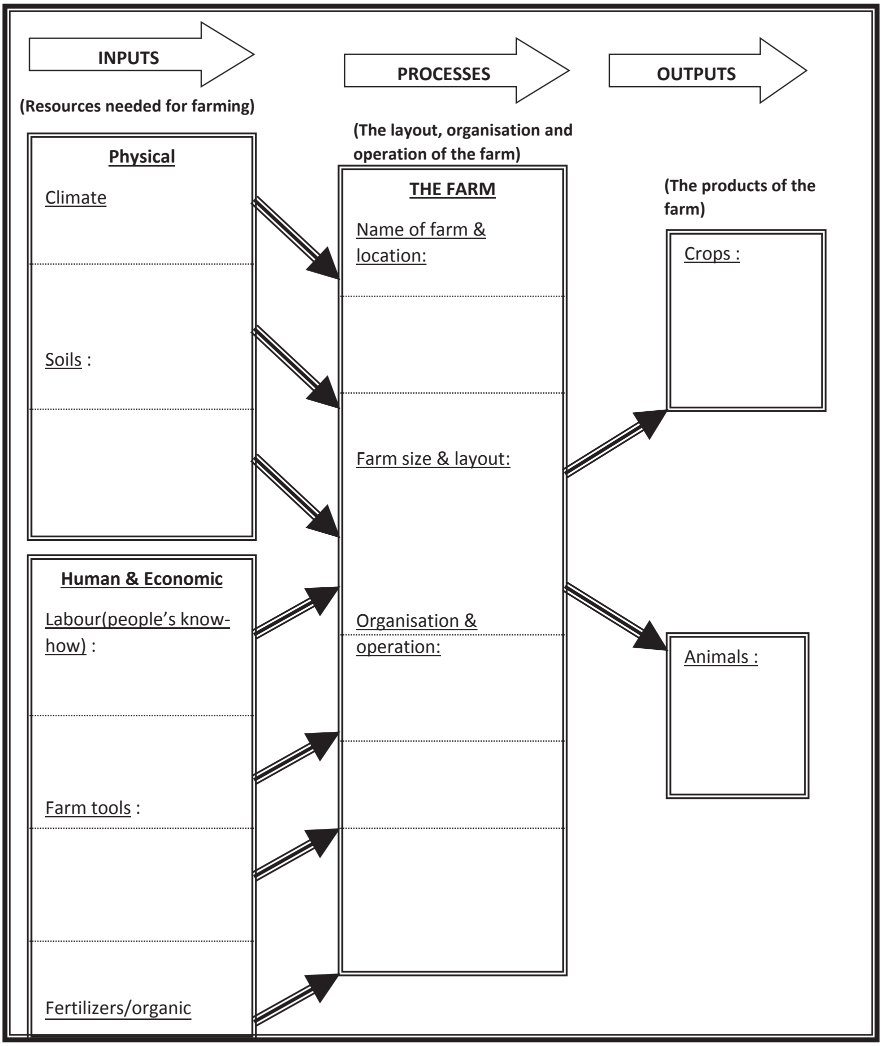

Fig. 11.2 Diagram of the farm as a system. (Adapted from Wuchu 2011)

The *Kejom Ketinguh* farms, though very small, are not very different from what is presented by Ruthenberg above. The little difference may lie in the fact that, as a system, the farm is thought of encompassing humans, animals, plants and the soils. Figure 11.2 brings out the farm as a system, showing farm inputs, processes and outputs.

The diagram shows that the farm has related elements of inputs, processes and outputs. Concerning inputs, which are the resources needed for farmers, there is first the physical elements of the farm. Physical elements are climate, soils, relief and vegetation. All these physical elements contribute greatly to the welfare of the farm.

To exemplify, climate is very vital in determining when to cultivate the farm, where and how to rear livestock, when to plant and when to harvest (Nkengim, 2010). In fact, we are not new to what a change in climate has done to crops and animals around or far away from us. Glaring cases around us are recurrent in the Far North Region where prolonged absence of the rain distorted the farm as a system, exposing it to drought, thus withering crops and killing livestock, which were components of the farm. We can also cite cases of climate troubles in Somalia, Sudan, Ethiopia and Kenya. Most often, these climatic hazards sometimes affect the crops planted on the farm.

The soil as a farm input is also vital, this is because plants like animals live and grow from or on soil. The success of the farm largely depends on the nature of the soils. Poor soils lead to poor crop harvest and vice versa. Again, the soils depend on the management mechanisms put in place by the farmers to restore or maintain its fertility (Wuchu, 2011). Overusage and overgrazing, for instance, drains almost all, if not, all the soil nutrients, thereby rendering it infertile for plant growth. Our study area is characterised by fertile humus soils at the lowlands and almost leached soils in the highlands where grazing of cattle is carried out by the Fulani people. The grazing activity exposes the soil to rain water erosion. In fact, it was observed that in certain areas in Sabga, the soils were outcropping revealing the leached nature of the soil.

Other physical inputs of the farm on the diagram are relief and vegetation. We have observed how relief determines the growth of some crops. To recall, Irish potatoes prosper in the highlands where the climate is cold, while cocoyams (*Colocasia esculenta*) do well in low swampy lands. Vegetation too serves as humus or organic fertiliser for the farm (Nkengim, 2010). This is when the leaves of trees or grass fall on the soils and get rotten. In addition, vegetation protects the environment of the farm since it can serve as a windshield to crops. However, some vegetation can serve as an impediment to food production. For instance, in *Kejom Ketinguh*, most people have developed the habit of using Eucalyptus as boundary trees. Eucalyptus (a fast-growing evergreen Australasian tree valued for its wood) has been proven a problem in areas where food is produced. This is because it drains a lot of water from the soil, which can be used by food crops. In fact, experts during fieldwork opined that Eucalyptus consumes more than 40 l of water each day. At this rate, the nearby crops are deprived of water especially during the dry season and can wither, thereby exposing farmers to food shortages.

After describing the physical inputs of the farm, let's turn now to the human and economic inputs. First, knowledge of farmers is a vital element as far as farm inputs are concerned. This is an intangible input, which is most often forgotten when looking at the non-physical resources of the farm. The know-how of farmers in relation to the seasons to plant, the tools to use and the management of the whole farm system help the farm to remain stable (Ngwe, 2007). This knowledge is drawn from the culture of farmers in question. In our study area, where subsistence farming respects customary practices, the knowledge of farmers becomes an important element as far as resources needed for the farm are concerned.

Second, labour is another resource needed for farming. How do farmers organise for labour? Do they hire or make use of family ties? As such, labour stands the chance in making a difference in the size and the number of the farm plots to be cultivated.

Third, farming tools and manure are also some of the inputs of the farm. Farming tools may be simple as a stick, or as sophisticated as a tractor. The only thing behind the minds of farmers is productivity. In our area of study, rudimentary tools such as hoes, cutlasses are used for food production (Iyegha, 2011). A draught animal, which was once introduced, has been left in the hands of an insignificant number of people (Prinz and Franz, 1987). Throughout fieldwork, we were able to identify only two people with draught animals. They use the animals mostly for the transportation of foodstuffs rather than ploughing. Manure too can be organic or inorganic.

Fourth, assistance from the government can also be categorised as farm input since it supports farmers to increase yield per unit. Assistance is usually in the form of credits, subsidising prices in the market to enable farmers to buy other farm inputs like fertiliser and tools (Ngwe, 2007). Equally, since the government is not the sole agent of development, other stakeholders like NGOs can also assist in food production through their technical know-how, sensitisation on improved farming practices. With the introduction of farming technological innovations, NGOs and the government are active in improving yields in order to ensure food security around the area. What is described above culminates to form what one can call farm processes. That is the physical, the human and economic resources for farming as shown on the diagram.

In the farm proper, there are certain activities that need to make us call it a farm; the layout, organisation and operation of the farm. Talking about layout, one has to think of the name of the farm, location and size. All these elements of layout characterise a farm in *Kejom Ketinguh* and enable farmers to identify their farms. Following the opinion of some informants, each farm has a name. Either this name is descriptive or it is a name relating to the quarter in which the farm is found. Besides, the name was understood to go alongside the location of the farm, some farms are nearer while others are very far from settlements (Iyegha, 2011). The size of the farm in *Kejom Ketinguh* was noted to be small. The farmers blame this on the high fragmentation of land due to the strict land tenure system.

Organisation and operation too are some of the aspects that make up a farm. How farmers are organised, what are the operations or farming practices going on in the farm? As represented on the diagram, all these are elements that are carried out on the farm to maintain the farm as a system.

Also, the farm is determined by the type of farming system. Referring to the diagram above, the farm is classified as being intensive, subsistence, arable, pastoral or mixed. The type of farm we are exploring in our study is the mixed crop farming system, which is more or less subsistence and intensive at the same time. Equally, there are, however, pastoral activities going on in the farm by farmers who own domestic animals and cattle.

From the farm, inputs and processes, what is expected of the farm is output. Output in the diagram can be either crops or animals. This output depends on the inputs and the processes of the farm. If inputs are poor, the farm will not be able to process, hence poor outputs. On the other hand, if inputs are good then the farm can process well, hence good outputs (Balgah et al., 2011). The methods of farming are still very rudimentary to boost about strong farm that can produce a significant output. Since most farmers produce food for subsistence, the output is not very substantial. Even animal production is not very different from food production despite the uptake of farming technological innovations. It is worth examining the types of farming techniques that used to ensure food production, before innovations were introduced in Kejom Ketinguh.

11.5 Traditional Farming Techniques

Data from the field enriched our knowledge on farming techniques or practices in *Kejom Ketinguh*. In fact, through observation and interview, it was made known to us that most people of *Kejom Ketinguh* still practice traditional farming techniques despite the uptake of farming technological innovations by others. These traditional farming techniques are presented as follows:

*11.5.1 Slash and Burn (***kenkoh***)*

This is a method of preparing a piece of land for farming. Here, the people clear the grass and allow it to get dry for a few weeks (Tekku, 2005). Later, the grass is gathered and burnt in order to prepare the plot for planting. In some cases, as observed, the ridges are formed without the grass while in other cases, the soil is mulched and planting is done with the coming of the first rains. This is common during January and February, which are cultivating periods in the village. It was also made known to us by some informants that the grass was burnt to make it easier for the ridges to be formed, while others simply concluded that they respect the old practices of disposing of bushes: a practice believed to have been handed down from their forefathers through generations.

This technique of farming is practised mostly in the dry season in areas where the plot has been fallowed for some time but has been covered by thick vegetation. However, this method of cultivation is still widely upheld in our area of study despite the introduction of farming technological innovations. What the farmers might not notice is the imbalance they create on the agro-ecology after the grass has been slashed and burnt (Altieri, 1995). This imbalance reduces the natural fertility of the soil provided by vegetation thereby rendering the soil infertile. Consequently, yields decrease in subsequent years thereby exposing them to a situation of food insecurity.

One respondent tried to justify this practice by observing that

> Sometimes the planting season is fast approaching and we have not finished preparing all the plots for planting. The plots that we are unable to finish on time, we burn the grass on them because it is the fastest way to keep the grass away. Mr. James, aged 43, farmer in *Tingeh* Quarter, 2 September 2011.

Figure 11.3 shows a farm after some perennial crops have been harvested. One can see green vegetation and the residues of maize after harvesting. This is a typical rudimentary farm in Kejom Ketinguh.

The picture above depicts plant residues on the farm pending slashing and burning to prepare for another farming season. Such farms are common in *Kejom Ketinguh* after corn, especially, has been harvested.

*11.5.2 Ankara (***nfuih***)*

This appellation is common in the vocabulary of farming in the entire North-West Region. In *Kejom Ketinguh*, this appellation is referred to as *nfuih*. Here, the bush is cleared using cutlasses and hoes. The cleared grass is gathered in heaps, a greater part of it covered with soil and fire is introduced on the grass beneath the soil. The grass and the soil burn for 3 days or more and is allowed to cool and then soil is added on the corner of the ridge. The middle of the ridge is left open with the ash that is left after soil and grass have been burnt (Dieter and Franz, 1987). With the coming of the rains, crops are then planted on the burnt ridges, which usually turn reddish when rain falls on them.

This cultivation method is only productive during the first year, but as time goes by, the plants rapidly drain the nutrients in the soil. This turns the soil unproductive. This method of cultivation was observed to be practised by most farmers despite the introduction of improved ways of managing composts. Some of them declared that: *'the method helps to enhance the fertility of the soil, thereby increasing yields'*. This

Fig. 11.3 Farm after some perennial crops are harvested. (Source: Author, 28 December 2011)

is, however, evident only in the first years of planting season as already mentioned; the years that follow, the soil becomes impoverished, thus eventually exposing the local population to food insecurity (Mbongsi, 2011).

*11.5.3 Ridging Along the Slopes (***ngwan-medieuh***)*

This is a method of placing ridges along the slopes instead of across the slopes. This method was observed in areas where the slopes were steep and farmers find it difficult to stand and build the ridges (Ruthenberg, 1976). With the absence of large tractors to cut terraces, they are forced to place the ridges along the slopes. This technique of farming is still practised despite the introduction of improved methods of farming like the use of contours, planting of shrubs that can hold the soils in steep areas. Farmers who work in such areas express grief on the fact that land has become very scarce thereby pushing them to the margins where they expect to produce for themselves and their children (Goheen, 1996). Others told us that: *they had no choice since the entire land is characterised by slopes, they are forced to cultivate on it*. *Chuku*, *Chua*, *Kekung*, *Tingeh*, *Kekong* quarters were some of the areas where this method of cultivation was observed. The artificial gullies created between the ridges serve as a passage for rainwater during the rainy season.

Considering the high amount of rainfall registered in this area, the soils and its nutrients are washed through the artificial gullies created by farmers and deposited on the farms found on the plains, thereby exposing the slopes to low yields (Nkengim, 2010). Sometimes, farmers who cultivate on the slopes do not understand why their crops are impoverished, while those on the plain just below theirs might be flourishing. Most families in this area who depend on the above-mentioned farming methods are exposed to food shortages hence food insecurity throughout the year (Obasanjo, 1989).

A farmer complained to us during an interview session: '*I do not understand why my crops could not do well while my neighbour's crops placed just below the hills were performing well*' Lowain Martha aged 39, *Timinshui* quarter, 2011. What this farmer failed to understand was the fact that the soil nutrients on her plot were constantly washed by rainwater each year and deposited at the gullies below that served as water passages.

11.6 Types of Farming Technological Innovations

These innovations are many and carry different objectives. Some are aimed at improving on the farming practices, while others concentrate on improved seedlings and wide spread sensitisation on information provision in relation to farming. This section handles some of the innovations that farmers were exposed to in the course of research. These innovating methods are aimed at improving food production thereby ensuring food security not only in *Kejom Ketinguh* but also beyond.

11.6.1 Draught Oxen Farming Systems

This farming system was introduced in the North-West Region and specifically in *Kejom Ketinguh* in the late 1980s. The innovation in this project was the adoption of animal traction to subsidise manpower on the farm. Farming technological innovations introduced under the above project became known as the *Bamenda model* (Prinz and Franz, 1987). This innovative model was constituted essentially with local resources, such as cattle, wood and metal.

The key elements in this so-called *Bamenda model* were the introduction of draught oxen, erosion control with contour bunds, prevention of soil-turning ploughing and the incorporation of agro-forestry as part of the farming system. 'This style employed the available knowledge of the local people that led to the incorporation of many people into the production of food and lesson human labour by introducing animals that could till the soil' (Prinz and Franz, 1987). This new adapted farming system proved well from the inception as farmers who embraced it began experiencing some improvements in their yields. The improvement in their yields was a positive sign ensuring food security throughout the year.

11.6.2 Genetically Modified Seedlings

Improved seedlings have been one of the ways that farming is being innovated in Kejom Ketinguh. These genetically modified seedlings include hybrid, disease resistant, disease free and early maturing species (Prevost, 1997). Some informants identified some modified species of Irish potatoes (solanum tuberosum) such as Superia, Jacob, Bambui Wonder, IRAD 2005 and Tuberia. Though some farmers still cultivate the traditional species whose seedlings are obtained through propagation, others embarked on the new species. Advocates of the traditional species argue that they are not resistant and get rotten once harvested. In maize *(Zea mais),* a new hybrid species noted was the *Kaisai*. The seeds were believed to be of high yielding species and the grains were thought to be more attractive than those of the *Mambela* and *Ngona* species that were previously cultivated. These maize species are short and confirmed to be resistant to weevils attack, the cob smut as well as the maize diseases that usually destroy the crop on the farm. The introduction of these improved species of different crops was aimed at improving the yields per year thus ensuring food security.

11.6.3 Integrated Organic Farming

In this system of farming, farmers were trained to make use of domestic animals (pigs, goats, fowls, rabbits and sheep) as part of crop production. These domestic animals lived in pens constructed by the farmers to enable the animals concentrate their droppings in a particular area so that it can be easy to carry with either a spade or a hoe (Williams et al., 1994). The droppings of these domestic animals were mixed with the farm residues to create manure (biofuel) which was put on the farms to improve on the soil fertility, especially in areas where the soil was completely drained of its nutrients due to over-farming. This method of farming goes a long way to increase productivity, thereby ensuring food security.

11.6.4 Sustainable Farming Practices

Agricultural extension workers sent by the Government and some NGOs made this farming practice known to the farmers through training and sensitisation. In this innovative farming practice, some traditional farming practices of slash and burn *(Ankara)* and ridging along the slopes were discouraged (Reijntes et al., 1992). Farmers were then trained on improved farming methods like slash and mulch, ridging across the slopes, which were thought to conserve soil fertility for a longer period than slash and burn. It should be recalled that in the slash and burn practice, all the grass that was cleared was burnt or partially covered with soil and burnt to form what is locally known as '*Ankara'* which was used to plant cocoyams. It was observed that these innovated farming practices were gradually gaining ground in the village thus making it possible for food security.

11.6.5 Improved Animal Species and Techniques of Rearing

This involved the introduction of hybrid species of animals that were resistant, multiplied rapidly and could produce a high quantity of milk daily. Some of the hybrids species are crossed with local species in order to produce more resistant species adapted to the environment. These domestic animals are also supported by improved techniques of rearing which range from improved pasture, night pens, modern drinking points, improved pasture and vaccination (Naylor, 2008). Some of the common species of livestock and improved rearing techniques introduced in the area of study are summarised in Table 11.2:

The introduction of this improved animal species and techniques of rearing was embraced by a significant number of the farmers. Besides ensuring milk and beef throughout the year, the dropping of the animals is in turn used as manure to fertilise

Table 11.2 Improved animal species and rearing techniques in Kejom Ketinguh

Animal types	Improved species	Improved techniques of rearing
Cattle	Hostein Boran Fresian Jersey Heifer	Improved paddocks Night padlocking Modern drinking points Cross breeding Vaccination
Pig	Large while Land race Chester	Elevated pigsty to permit air circulation Improved pig feed Vaccination, cross-breeding
Goat		Well-constructed goat enclosures Improved paddock Night padlocking Modern drinking points Vaccination, cross-breeding
Chicken	Single combed white Keghorn Dark Cornish	Incubator to produce chicks Constructed chicken house in homestead
Rabbits		Well-constructed cages for rabbits
Guinea pig		Well-constructed cages for guinea pigs
Sheep		Well-constructed goat enclosures Improved paddocks Night padlocking Modern drinking points Vaccination Cross-breeding

Adapted from Wuchu (2011) and field work, 2011

the farms where crops are cultivated. This method of farming is of utmost importance because it boosts productivity, hence ensuring food security.

11.6.6 Crop Rotation

This is traditional farming, which consists of changing the type of crop grown in a plot each year. Crop rotation is said to be an ancient cultural farming practices reported in several early civilisations in Africa and Asia. Usually, normal rotation periods are 4 years, but sometimes they go up to between 6 and 8 years (Christianity, 1986). This longer period is better in order to accumulate the nutrients in the soil. In *Kejom Ketinguh*, crop rotation is gradually introduced with the coming of farming technological innovations and is carried out where there is enough land for crop cultivation. One can find few examples of this system in the Chuku area where gardening is generally practised. Following knowledge from the farming technology, they rotate leeks, shallot and tomatoes, onions, beetroots and carrots, with the aim of keeping away pests in order to ensure food security.

11.6.7 Paddocking

This type of farming involves integrated use of animals or livestock for food production. In *Kejom Ketinguh,* this system is enhanced by the presence of the Fulani who own cattle. The farmers and the Fulani cattle rearers enter into a sub-method of farming known as paddocking (Mclntire et al., 1992). Food crop producers construct fences on their plots and the Fulani keep cattle there for a period of 1–2 months for animal droppings, which will eventually fertilise the piece of plot. The cattle droppings left on the plot are a useful organic manure to increase soil fertility and boost yields. This plot is eventually used to cultivate onion, vegetables and maize for like 2–3 years before the soil is drained of its nutrients. Paddocking helps boost productivity, thereby ensuring food security in this area. Figure 11.4 shows cattle in an enclosed bamboo pen, where they usually spend the night. The cattle are enclosed in the small pen to eventually use their droppings as manure for crop cultivation.

In Fig. 11.4, one can see a fence constructed on a piece of plot to keep cattle at night. This plot will later be used for the cultivation of garden or any crop as desired by the proprietor.

The system of integrating crops and animals in this region is far from what is done in the western world. Animals and crops seldom share the fields nor do the farmers cultivate fodder solely for the animals (Bojo and Cassels, 1995). Animals are allowed to graze in the fields far from the farms during the day and, at night, they are locked up in wood and bamboo pens. The main idea behind paddocking as a system is to derive as much benefit from the animal droppings for the farms as possible (Naylor, 2008). This system is mostly practised around the *Sabga* and *Kwighe*

Fig. 11.4 Cattle locked in with a bamboo fence (night pen). (Source: Author, 25 September 2011)

area where *Fulanis* and other *Kejom* people own cattle. This system has also ensured food increase, hence stabilising food security in the zone under study.

11.6.8 Slash and Mulch

This is a method of cultivation, whereby grass is cleared, allowed to dry and gathered on the furrows. It is then covered with soil and arranged as ridges. The ridges are then allowed as such until planting is done with the coming of the first rains (Speirs and Olsen 1992). Through observation and interview during fieldwork, we understood that this method of cultivation is common in certain parts of *Kejom Ketinguh*, especially in plots where farming is continuous and without fallow. Unlike the other methods of cultivation formerly mentioned, this method of farming is said to have been inherited from farming technological innovations, (data from informants). Others thought that this method existed before the coming of farming technological innovations. This technique of preparing the farms is still common and agents of farming innovations insist that farmers employ this technique because it sustains the fertility of the soil, hence increases yields.

11.6.9 Agro-forestry

This is a system of farming which entails the planting of fruits trees or shrubs on the contours or boundaries of farm plots (Williams and Chew, 2008). These trees can be mangoes, pear, plums and orange trees. Sometimes, nitrogen-fixing trees that can help to fertilise the soil for the growth of perennial crops like maize, beans and Irish potatoes are equally planted. Besides providing the farmers with foods, these trees also serve as windshields to the perennial plants especially during the rainy season when thunderstorms are very common. This innovative system was introduced by PAFSAT in the entire North-West Region and *Kejom Ketinguh* in particular in the late 1980s.

Figure 11.5 shows an agro-forestry section of a small farm. In the farm, tree crops such as oranges, avocado, bananas and mangoes are planted among food crops. In fact, there is a combination of forest and agriculture. The forest produces fruits that can be sold by the farmer to sustain subsistence.

In Fig. 11.5, one can notice agro-forestry visible in the background. One can see bananas, plantains, avocado and mango trees growing together with perennial crops. It is important to note that the uptake of these innovative techniques have gone a long way to increase food production.

Fig. 11.5 View of an agro-forestry sector of the small farms. (Source: Author, 29 December 2011)

11.7 Integrating Cultural Values and Practices with Farming Technological Innovations

As discussed earlier, farming innovation means to change attitudes and practices related to farming. It also means to adopt and change to new ideas (Balgah et al., 2011). Associating cultural practices to farming technological innovations takes diverse dimensions considering the fact that behaviour change, most often, takes a general process. Our concern here is thus to bring out cultural values that could be integrated into farming technological innovations for food production to thrive in *Kejom Ketinguh*. The following are therefore taken into account:

11.7.1 Compatibility of Farming Technological Innovation with Cultural Values and Practices

Cultural values are primordial in the existence of a particular community or village. Cultural norms shape the lives of many the people. Put another way, cultural norms determine what they think, the way they act and feel. Thus, the dos and the don'ts are controlled by their culture. Introducing a new element into this total setup of cultural values is likely to distort their way of life and most, if not all, of the people will prefer to be reluctant to the new elements. Hume (2006) has observed such a situation in the eastern regions of Madagascar and concluded, 'if the socio-cultural values of the people were not taken into consideration, the introduction of the new farming techniques may be doomed to failure'.

In *Kejom Ketinguh*, the initiators of farming technological innovations do not, in most cases, take into consideration the cultural practices and values of the people. Ideas about innovations are designed in the offices of the promoters and imposed on the communities. This is because the only thing that lingers in their minds is the problem identified on the field, hence they look for solutions without considering whether the farming innovations are compatible with the existing cultural values. Take, for example, the introduction of the MIDENO beans and corn seedlings as innovative species in *Kejom Ketinguh*. These seedlings failed to be adopted because the project did not take into consideration the culinary taste of the people. As such, most adopters rejected the new species because they complained that the beans were not tasteful like their traditional species, which were not doing well as far as production was concerned. Therefore, if farming innovations are compatible with the peoples' cultural values and practices, they will be enthusiastic to adopt, hence increase in food production will be ensured.

11.7.2 The Advantage of Farming Innovations to the People

In order to integrate farming technological innovations into the cultural concerns of the people, they have to perceive the relative advantage of the innovation. If they do not perceive the relative advantage of the farming innovations, it can be difficult for them to integrate the same in their cultural concerns, thereby rejecting it; as such, the rate of adoption of the innovation will be slow. This largely depends on their particular perceptions and their needs (Quaye et al., 2010). Take, for example, the *Kejom Ketinguh* people's perception of the origin of black smut that attacks maize or their perception on the causes of poor harvest. They might not embrace the farming innovations if practical demonstrations are not made to appeal to their senses. Without this, if the relative advantages of the farming technological innovations are not perceived, farmers might slowly adopt them, hence food production might face a downward trend.

11.7.3 Simple to Use

This is also important in integrating cultural concerns into the farming technological innovations. Farming innovations that are seen as complicated to know are most likely rejected. Knowledge that can be understood will be approved further quickly than the ones that will need the local population to acquire innovated abilities through education or training. Those ideas that are very simple to understand will be easily integrated into the cultural concerns of the people, thereby enabling most people to adopt the farming technological innovations.

In the 1980s, the introduction of integrated farming techniques using animal draught required a lot of training to understand (Prinz and Franz, 1987). Community leaders were required to choose people from farming groups that were intellectually viable to undergo training for 8 weeks. Those trained were the ones to come back and train the rest of the group members. This was not easy because most group members found it difficult to learn new skills, thereby thwarting the efforts of such an initiative in promoting food production in *Kejom Ketinguh* and beyond. As a reminder, these integrated farming techniques were introduced by PAFSAT under the auspices of GTZ using WADA as the implementing authority in the entire North-West Region.

11.7.4 Farming Technological Innovations Should Be Bottom-Up

Farming technological innovations that do not come from the people themselves are always difficult to be integrated into the cultural concerns of the people (Reijntes et al., 1992). Most farming technological innovations, like other innovations, are always imposed on the people in a top-down approach. This top-down approach does not take into consideration the values, taste, past experiences, needs and aspirations of the people. Consequently, such projects are bound to fail before they are implemented because their cultural concerns were not given attention.

Let us look at the Paddock system that was initiated with Fulani cattle herders and the non-Fulanis, for example. This system is succeeding because the people were at the origin of the innovation. This innovation seems to be widespread in the entire village, while other innovations like the Past-On-Gift initiated by Heifer Project International are still to gain ground because they need a lot of time and effort to raise the calf for it to be pregnant and deliver another calf to be passed on as a gift to another farmer. Thus bottom-up farming technological innovation can be very important in promoting food production since the cultural values and practices are used to determine the type of innovation to be adopted.

11.7.5 Farming Innovations Should Be Persistent

In order for farming technological innovations to be integrated into the cultural concerns of the people, farming innovations are supposed to be persistent, and should not fluctuate. A fluctuating farming innovation not only creates confusion in the minds of the adopters but also goes a long way to dissuade the innovation from being part of the peoples' cultural concerns (Naylor, 2008).

This fluctuating nature of farming innovations was very noticeable in *Kejom Ketinguh.* The innovators themselves seemingly did not have a clear-cut vision of what farming innovation they were out to implement. Sometimes, one had the impression that the innovations were on trial bases. This is because we noticed that in the domain of improved variety of seeds, for example, the farmers complained that they were introduced to new seedlings every year. Examples include Irish potatoes, carrots, beans and corn, just to name a few. This fluctuation makes it difficult for farmers to concentrate and understand the type of seedlings that can be very productive to adopt into their cultural concerns. This explains why yields are also fluctuating as far as food production is concerned.

11.7.6 Build a Network of Farmers Group

In order to capture the interest of the people to integrate innovations into their cultural concerns, a network of farmers' group is necessary. This network is necessary because information on farming innovations can be shared by word of mouth and daily conversations amongst farmers. If one group benefits or understands the relative advantages of an innovation, it can be shared with the other groups. During fieldwork, we noticed that the *Kejom Ketinguh* farmers had many farmers' groups. These farmers' groups sometimes went beyond farming to assist members financially. What seemed to be lacking with farmers' groups in *Kejom Ketinguh* was that they were not coordinated as a network. Each group operated independently of others, thus limiting the spread of farming technology through information and/or internal training within the groups. Thus, if networking is created between farming groups, it can enable them to integrate farming technology into their cultural concerns, leading to increased food production.

11.7.7 Observable Results

Observable results are those that are immediately seen or felt by the beneficiaries of the innovation. These observational results are instrumental for people to integrate innovation. If the people observe the outcome, they will surely adopt the innovated farming activities. This is because results that are perceptible wipe away doubts from people's minds and equally motivate people to discuss them, hence looking for means to be part of the process. The Paddock farming system initiated with the knowledge of farmers is a good example of an innovation whose results are visible. This is because cattle borrowed from herdsmen were kept tethered in night pens to drop their dung, which was later on used for the cultivation of a variety of crops, which, to the eyes of the people, are very productive. Thus, people saw the results of the paddock system almost immediately and as such easily adopted them as part of their cultural concerns, which is important to ensure increase in food security.

11.8 Conclusion

Traditional farming techniques affect the production of food in *Kejom Ketinguh.* Data collected from the field revealed that the *Kejom Ketinguh* traditional farming techniques affected food production negatively and that is why there was need to take up farming technological innovations. This is because the techniques contributed in destroying the soil nutrients rather than restoring them. Wuchu (2011) has also confirmed this fact in the *Tubah* subdivision. He demonstrated that the traditional farming techniques are partly responsible for the depletion of the soil nutrients in the Tubah subdivision, of which *Kejom Ketinguh* is part. Consequently, the fertility of the soil, which is meant for farming, is reduced. In the same line, Nkengim (2010) observed a similar situation in *Bimbia, Bonadikombo* forest area in the South-West Region. We gathered from the field that the *Kejom* people were very much glued to their traditional farming techniques, thereby destroying the soil nutrients that are meant for the production of crops. Njong (2001) remarked that: 'the *Bambui* people, a neighbouring village to *Kejom Ketinguh,* had showed signs of resistance to farming innovations and, as a result, most of them continue to practise their traditional farming which does not ensure food security all year round'.

Some of the traditional techniques we have examined in this chapter are the slash and burn, *ankara*, ridging along the slopes. These farming techniques or methods, practised by the *Kejom Ketinguh* people, go against the norms of the introduced farming technological innovations. Also, due to limited financial resources, we observed that they employ traditional means of fighting against pests and diseases. These means are very limited in curbing pest and diseases that sometimes destroy the crops in the field.

Concerning farming operations, we brought out the different farming operations beginning from farm preparation through planting and then harvesting. All these operations as we witnessed, the cultural calendar that is respected for farming to be carried out was highly traditional, showing how innovations have been enshrined into the people's cultural norms.

Food production is a system or, better still, an institution that exists to play a particular function not only to the *Kejom Ketinguh* people but to other areas as well. The principal function of this system is to produce food that can that can ensure food security at all times.

In a nutshell, this chapter reveals the following: first, the uptake of farming technological innovations in the area of study has enabled increase in food production; second, food production, especially market gardening, is carried out throughout the year, irrespective of the season. Third, most traditional farming techniques, which are not productive, are gradually phasing out. Fourth, the adapted farming innovation practices are gradually integrated into the cultural mores of the *Kejom* people, thus making it more comprehensible for food production, hence securing food at all times for the people.

Another study can go further to study the impact of the adoption of agricultural technological innovations on agricultural growth in the village.

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Chapter 12
Food and Nutrition Insecurity in Africa: The Primary Drivers and Sustainable Strategies to Improve the Current Status

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12.1 Introduction

Africa is home to approximately 1.3 billion humans representing 16.72% of the World's population (Worldometer 2020). The continent is leading the number of malnourished people globally after Asia, estimated at 250 million people in 2020, and by 2030, the figure could reach 450 million (FAO et al. 2020b). Nevertheless, 412 million out of the estimated figure (450 million) of undernourished people would be from the sub-Saharan region of Africa (FAO et al. 2020b). The FAO defines food security as "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 healthy life" (FAO 2006). Inevitably, to achieve food security, individuals must have the means (income) to consistently access sufficient quantity, nutritious, and safe foods at all times. In other words, food security revolves around four concepts; availability, accessibility, utilization, and stability. "Food insecurity occurs when people lack regular access to safe and nutritious food for normal growth and development and an active healthy life" (FAO 2020b). More importantly, Africa could not meet the past Millennium Development Goals (MDG) targets for food security, and now all hands are on deck to attain the Sustainable Development Goals (SDG) 2 to End Hunger by 2030. On the contrary, the projection shows that Africa is not on track to end food insecurity by 2030 (ZEF and FAO 2020).

The frequency of food insecurity in Africa is the highest among the world's regions and more than twice the world's average (FAO 2020b). That aside, the reasons for the predominance of food insecurity include weak and worsening economic conditions, politics and policies, drought, insecurity, migratory pests, flood,

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dry spells, archaic agricultural practices, and an increasing number of conflicts (Gute and Nkosi 2021; ZEF and FAO 2020). Moreover, out of the 28 poverty-stricken nations globally, 27 are African nations (all from sub-Saharan Africa), with 30% living on USD1.90 per day or less (FAO et al. 2020b; Patel 2018). Additionally, the COVID-19 pandemic is expected to worsen current food insecurity issues in Africa, but the devastation that would cause is uncertain (FAO 2020c). Suitable sustainable strategies that best fit each African region would effectively manage food insecurity. This chapter provides a broad overview of the primary drivers of food and nutrition insecurity in each African region about food accessibility and availability and suggests strategies to attenuate their effect.

12.2 Overview of Food Security in Africa

Hunger in Africa substantially worsened between 2019 and 2020, with undernourished people increasing from 89.1 million in 2014 to 281.6 million in 2020 (FAO et al. 2021), while the increase could be due to the effect of COVID-19, among other inherent factors. The Global Hunger Index 2019 report classified Egypt, Morocco, Tunisia, Algeria (Northern Africa), Ghana and Senegal (Western Africa), Gabon (Central Africa), and South Africa (Southern Africa) as having moderate hunger and undernutrition, while other countries have severe to extremely alarming hunger and undernutrition (von Grebmer et al. 2019). The prevalence of food and nutrition insecurity has been consistent for the past 18 years in Eastern and Central Africa, whereas hunger worsened over the 2014–2018 period in Western and Central Africa (FAO et al. 2020a). Subsequently, the levels and trends of persistent hunger have varied in different parts of Africa. More importantly, Eastern Africa bears the severest brunt of food insecurity and the highest number of undernourished people in Africa (125.1 million), representing 44.4%, followed by Western Africa (75.2 million) representing 26.7%, Central Africa (57.1 million) representing 17.4%, and Southern Africa (6.8 million) representing 2.4% of the undernourished people in the continent (FAO et al. 2021). To elaborate on the severity of food insecurity in each African region, the Integrated Food Security Phase Classification used to demonstrate the different levels of severity of acute food insecurity are IPC 1 (None/Minimal), IPC 2 (Moderate/Stressed), IPC 3 (Crises), IPC 4 (Emergency), and IPC 5 (Catastrophe/Famine) (Integrated Food Security Phase Classification 2021d).

Djibouti, Ethiopia, Somalia, Eritrea, Sudan, South Sudan, Kenya, and Uganda, constitute the horn of Africa (HOF), with some of the poorest and most food-insecure people in the world, and half of those in need are children (Martin et al. 2018). In 2019, before the pandemic, the Intergovernmental Authority on Development categorized 27.6 million people from HOF in crises, or catastrophe levels of acute food insecurity, with Ethiopia having the highest share of eight million, Sudan (5.9 million), and South Sudan (seven million) and identified them as part of the top ten nations in the world with food crises (The Intergovernmental Authority Development 2020b). Similarly, The Intergovernmental Authority

Development (2020b) estimated 13.6 million children in East Africa below the age of 5 as stunted, with Ethiopia leading with the highest figure, followed by Sudan and Uganda. In addition, South Sudan is still in the exact situation of rampant food insecurity as food security has deteriorated since 2012, leaving almost half of the country's population in food consumption inadequacy (Famine Early Warning Systems Network 2018).

West Africa is characterized by poverty, instability, social strife, extreme demographic pressure on mineral resources, and severe environmental degradation (Allen 2018). Out of the 75.2 million undernourished people in Western Africa, 11.4 million from Burkina Faso, Chad, Nigeria, Mali, and Sierra Leone have been estimated and classified into the Integrated Food Security Phase Classification (IPC 3–5) and are in immediate need of food assistance (SWAC/OECD 2020). Data from Cadre-Harmone (An African tool for analyzing the severity of food security) showed that Northern Nigeria is a step away from famine, with 13 million people estimated as food insecure in the lean season of 2020, likewise, an estimate of 13% and 23% of the population of Liberia and Sierra Leone, respectively, were food insecure in the summer of 2020 (World Food Programme 2021a).

Central Africa comprises nine countries; Angola, Equatorial Guinea, Gabon, Chad, Cameroon, Central African Republic, Democratic Republic of Congo (Kinshasa), The Republic of Congo – Brazzaville, Sao Tome, and Principe. This food insecurity in this region has been consistent for the past 18 years, indicating constraints on food availability and accessibility (FAO et al. 2020a). The Central African Republic has an unequal Global Hunger Index (53.6) in the world, with 60% of the people undernourished and half of the children stunted (von Grebmer et al. 2019), which has caused severe concern (European Commission 2020). The Integrated Food Insecurity Phase Classification reported that 1.9 million people in the Central African Republic were experiencing IPC 3 or above in September 2020, while 408,000 people require Humanitarian Emergency (IPC 4), and in the lean period (May–August 2021), IPC estimated food insecurity figure to rise to 2.31 million people (Integrated Food Security Phase Classification 2020a).

North Africa is an economically thriving region that consists of seven countries; Libya, Morocco, Egypt, Sudan, Algeria, Tunisia, and Western Sahara. Excerpts from the Global Hunger Index showed that only Libya and Sudan experienced severe hunger and undernutrition challenges (IPC 3–5), while the rest were categorized as moderate levels (von Grebmer et al. 2019). More importantly, political instability has a worrying implication for food insecurity in Northern Africa (Ayeb and Bush 2019) because the region depends on food imports (the highest in the World) to attain food security (Tull 2020). Nonetheless, despite high subsidies on imported food in Libya and Sudan, citizens still experience food insecurity (FAO 2020a). The Integrated Food Security Phase Classification analysis published that 7.3 million Sudanese (46.5 million analyzed population) are at a high level of acute food insecurity (IPC 3 or above), where about 5.5 million are in food crises (Integrated Food Security Phase Classification 2021c). In the same way, 53 out of 79 counties in South Sudan are experiencing severe acute food insecurity (IPC 3+), estimated at 6.35 million (52.6% of the population), out of which 92,000 people are experiencing Famine (IPC 5) in six counties (Integrated Food Security Phase Classification 2021b). Similarly, the World Food Program survey reported poor food security indicators in the Eastern part of Libya (World Food Program 2021b), and 11 out of 100 Libyan populations are estimated to be food insecure (Nouh 2021).

Southern Africa comprises six countries: Botswana, Eswatini, Lesotho, Namibia, South Africa, and Zimbabwe. This region is characterized by increasing population growth, diminishing natural resources, persistent drought, and floods, which heighten food insecurity (SDAC 2019). Zimbabwe, Lesotho, and Botswana were classified under the Global Hunger Index as experiencing severe hunger and undernutrition challenges (IPC 3 +), whereas the rest experienced a moderate-level hunger index (von Grebmer et al. 2019). In comparison, Zimbabwe has the highest ratio of food-insecure people to the population in Southern Africa, and half of its population (7.7 million) is at risk of starvation (FAO 2021b). As of November 2020, 2.61 million people (27% of the analyzed population) living in rural communities of Zimbabwe are experiencing IPC 3 or above, while 2.9 million people are experiencing IPC 2 (Integrated Food Security Phase Classification 2020b). Correspondingly, food security has been a long-standing challenge in Lesotho as well, a country with about 2.2 million people, and more than half (57%) of the population live on less than a dollar a day (World Food Programme 2020). The country's slow economic growth impinges on household income and economic capacity to attain food security (FAO 2021b). Approximately 350,000 people face severe acute food insecurity (IPC 3 and 4) (Integrated Food Security Phase Classification 2020b). Likewise, approximately 290,000 people face food insecurity (World Food Programme 2019), including 14,000 people in IPC Phase 4 in Namibia (Integrated Food Security Phase Classification 2020c). In comparison, the prevalence of food insecurity in Africa differs, perhaps because of the degree of influence of the drivers of food insecurity in each region.

12.3 Primary Drivers of Food Insecurity in Africa

12.3.1 Insecurity

Violent conflicts exacerbate food insecurity by limiting food production, distribution, availability, and accessibility, leading to food deprivation (FAO 2017). More importantly, it increases unemployment, reduces households' ability to access food (World Food Programme 2021b), and increases the severity of the food insecurity indicator (FAO 2017). Survey statistics have shown that access to food aid and distribution in conflict-affected communities decreased with increased armed group presence (Tranchant et al. 2019). Nevertheless, the impact of violent crises on food security varies depending on the duration of the conflict and its effect on livelihoods (Arias et al. 2019; Martin-Shields and Stojetz 2019). Anderson et al. (2021) showed that violent crises only significantly impacted food security in Nigeria and South

Sudan, while they had no significant effect on other countries included in their study (Ethiopia, Somalia, Kenya, Sudan, and Mali).

The horn of Africa has a consistent record of violent conflicts within countries and across borders, and conflict crises have been strongly interlinked with food insecurity in the region (Abebe 2021). For instance, community clashes and violence have left 8.5 million people food insecure in South Sudan (seven million) and Uganda (1.5 million) (The Intergovernmental Authority Development 2020b). Additionally, the growing tension in Northern Ethiopia has escalated to violent conflict in Tigray, Amhara, and Afar communities, leading to the loss of livelihood, displacement, and aggravated food insecurity (FAO 2021a). The conflict increased the population of people in food insecurity crises from 61% in May to 74% in September 2021, reaching 3.9 million people (Integrated Food Insecurity Phase Classification 2021a). Consequently, the food insecurity challenges in Ethiopia increased the prevalence of Global Acute Malnutrition (at 85%) in the refugee camps, which exceeds the United Nations standard (10%) for refugees (FAO 2020d). Similarly, violent conflict has been associated with food insecurity in Northern and Central Somalia (Anderson et al. 2020). The renewed clan-based conflict affects Mogadishu and Bosso, and has driven double food taxation, added strain to household purchasing power, reduced food accessibility, and humanitarian aid (FAO and WFP 2019). Similarly, violent conflicts have exacerbated food insecurity in South Sudan. A study utilized 7500 multiscore satellite images to investigate the percentage of abandoned farmland due to armed conflict. It revealed that 16% of cultivated farmlands were abandoned between 2016 and 2018, which could have improved the food security and livelihood of a quarter of the population living in the southern state of South Sudan (Olsen et al. 2021). Even though large-scale conflict has reduced in South Sudan since the 2018 peace treaty, intercommunal violence, cattle raiding, kidnapping, and other localized conflicts are still rampant, affecting livelihoods and food security (Integrated Food Security Phase Classification 2021b). The SMART nutrition survey estimated that about 1.4 million children in different parts of South Sudan would suffer from acute malnutrition in 2021 (Integrated Food Security Phase Classification 2021b).

Armed conflict is a significant primary driver of food insecurity in West Africa (Ujunwa et al. 2018; Tranchant et al. 2019). Moreover, populations in Liberia, Sierra Leone, Côte d'Ivoire, Burkina Faso, Guinea Bissau, and Northern Nigeria are concentrated with acutely food insecure people due to violent conflicts that have persisted over two decades (Martin-Shields and Stojetz 2019; SWAC/OECD 2020). To elaborate, the upsurge of war between Boko Haram and Nigeria's Government started in 2009 (Famine Early Warning Systems Network 2022) and has disrupted agricultural activities, humanitarian access, and caused displacement (Kah 2017), consequently displacing over 2.1 million people in the Northeast in February 2021(Famine Early Warning Systems Network 2022). Then again, using the current food insecurity data in the region, Famine (IPC 5) is imminent, especially in hard-to-reach areas of the Northern and Central part of Nigeria (Famine Early Warning Systems Network 2022). Likewise, insecurity constitutes the principal food insecurity driver in the Central African Republic, especially in Bambari, Batangafo, Bria, and Kaga-Bandoro communities, and has interfered with trading activities, destroyed the livestock sector, and further pushed up food prices. (FAO and WFP 2019). The insecurity crises in Congo remain volatile and have heavily impacted food security and increased the refugee camp's global acute malnutrition. In addition, insecurity-related issues disrupted import food trade flows in some parts of the Central African Republic's Doula-Bangui region, causing food stock depletion in supply areas and pushing up food prices (FAO and WFP 2019).

Conflicts and protests across Libya amplify food insecurity through physical and natural capital destruction, displacement, and unemployment (FAO 2017; World Food Programme 2021b). Customarily, Libya was once categorized as an upper-middle-income economy before the war (FAO and WFP 2011). It had a booming oil industry, growing and construction services, but low agricultural productivity (FAO 2019). Then, agriculture accounted for 3% of the economy, and food security was achieved through 80% food importation before the war (FAO 2019). However, in the aftermath of the 2011 war and constant violent conflict, more than 92% of households in Libya now consume what they grow as against 22% before the war in 2010 (FAO 2019) to minimize food insecurity shock. Nonetheless, the conflict crises in thirty of the thirty-two districts of Libya vary (Carboni and Moody 2018), and so does the food insecurity level. Eighty percent of the population of Alkufrah are in IPC 5, 60–80% of the population in six districts require food emergency (IPC 4), while 40–60% in three districts are in IPC 3 (FAO 2019).

12.3.2 The Impact of Insecurity on Displacement

The reoccurring terrorism and inter-community violence have displaced millions of people within their countries, whereas some have become refugees in neighboring countries (FAO et al. 2020a; World Food Programme 2021a). For instance, insurgents murdered 110 rice farmers in December on their farmlands in Borno state in Nigeria, and they have killed over 30,000 people since 2009, displacing more than 2.7 million people (FAO 2020a; Paquette 2020). Similarly, approximately 921,000 people were recorded in June 2020 to have fled Burkina Faso, 24,000 in Mali, 489,000 in Niger (United Nations 2020c). To sum up, West Africa hosts 870,000 refugees and 4.9 million displaced persons in 2020, with 19.1 million people living in this region estimated to be food insecure during the lean period (United Nations 2020d). In the same way, UNHCR Protection and Monitoring Network recorded 190,000 population in 2019 in Somalia displaced due to conflict and insecurity (Famine Early Warning Systems Network 2020a). In contrast, five provinces are experiencing violent conflicts in Congo and have uprooted more than 35.2 million people from their homes (Integrated Food Insecurity Phase Classification 2021b). In addition, UNHCR reported about 2.3 million refugees in South Sudan, which excludes about two thousand refugees seeking asylum in the Central African Republic (UNHCR 2021), while about 2.3 million are internally displaced, primarily due to conflict (OCHA 2021).

12.3.3 The Impact of Insecurity on Food Price

High food prices impact low-income food-deficit countries already facing hunger and malnutrition, while it pushes more people to poverty and reduces access to adequate nutritious food (FAO 2008; Gustafson 2013). High food prices could prompt increasing demand for food and impact food availability (Kalkuhl et al. 2016; Wossen et al. 2018). Consequently, violent conflict impacts shocks on household income (Raleigh et al. 2015) and results in a less diversified diet due to a shift from highly priced protein foods such as meat and milk to cereal consumption (Hussein et al. 2021). For instance, a study showed that food price increase was associated with higher levels of violence in a regression analysis (Van Weezel 2016). In the same way, the post-election ethnic violence in Kenya was associated with an increased price and decreased quantities for maize and wheat prices in the country during this period (Gil-Alana and Singh 2015). Likewise, insecurity-related issues disrupted import food trade flows in some parts of the Central African Republic's Doula-Bangui region, causing food stock depletion in supply areas and pushing up food prices (FAO and WFP 2019).

12.3.4 Climate Change

Africa is warming faster than the world's average for many reasons (Berwyn 2020), and its impact varies from country to country (Serdeczny et al. 2017). Some regions are experiencing droughts, whereas some are affected by flash floods. Consequently, high temperatures are changing crop yield, as farming in Africa is dependent on natural precipitation and rainfall. Eighty percent of all international disasters are due to climate change (von Grebmer et al. 2019), whereas, on its own, it is a potential threat to food security (Richardson et al. 2018). It is essential to note that the impact of climate change alone on food security has been estimated to increase the number of people at risk of hunger in Africa in 2030 by 16 million (Mason-D'croz et al. 2019). Complementary to this, Intergovernmental Panel on Climate Change estimated negative yield on major food crops in Africa, indicating a 27–32% loss for maize, sorghum, millet, and groundnut for warming exceeding 4 °C or temperature above 30 °C (Niang et al. 2014; Schlenker and Lobell 2010). As an example, an ensemble of historical climate simulations and two process-based crop models were used to assess the historical climate change in West Africa. The report showed that the rise in global warming in West Africa by 1 °C between 2000 and 2009 led to an average yield reduction of 10–20% for millet and 5–15% for sorghum (Sultan et al. 2019). In contrast, Faye et al. (2018) investigated the effect of an increase in global temperature rise from 1.5 °C to 2 °C on maize, pearl millet, and sorghum yields in West Africa. The study reported only a 2% loss for maize and sorghum with 2.0 °C compared to 1.5 °C temperature, with no change in millet yields. Perhaps, climate change had a lesser effect on the crop yield in Faye et al. (2018) because the sustainable intensification strategy practice with the high use of fertilizer to reduce food insecurity was adopted. Faye et al. (2018) reported that the use of fertilizer (both limiting and non-limiting nutrients) increased yield by two to three times irrespective of the temperature rise. More importantly, climate change can worsen the nutritional value of food (von Grebmer et al. 2019), and by 2050, an estimate of 175 and 122 million people could experience zinc and protein deficiencies due to CO2 concentration's influence on climate change (von Grebmer et al. 2019).

Horn of Africa countries are prone to reoccurring droughts and dry spells and are easily affected by climate change and variations (The Intergovernmental Authority Development 2020a). Drought and flood wreaked havoc on farmlands in 2019 in some parts of East Africa and resulted in acute food insecurity for 13.2 million people (The Intergovernmental Authority Development 2020b). Likewise, East Africa recorded another high rainfall between March and May 2020 since 1981 following an already recorded wet 2019 rainfall (October to December), and this resulted in major floods in South Sudan and Somalia, and landslides in Kenya and Uganda, causing population displacement, crop damage, and subsequently resulted in food price inflation. In Tanzania, farmers have begun to notice the impact of climate change. A focus group, from Manyoni district, Tanzania, consisting of farmers reported a decrease in rainfall and an increase in temperature over the years, leading to decreased soil fertility, drying of water resources (Sawe et al. 2018), and impacted production yield. To illustrate, the outcome of a study showed a decline in production yield for four out of five crops in Basona Werana and three out of five crops in Efratana Gidim and Menz Gera Meder, Tanzania provinces (Alemayehu and Bewket 2016). In the same way, an increasing water deficit occurred in Ethiopia between 1982 and 2014 during critical plant growth stages, and most importantly, the water stress occurred in regions experiencing acute food insecurity (Brown et al. 2017). In short, between 55% and 70% of croplands in East Africa are affected by drought (Gustafson 2019).

Climate change influences the availability and distribution of agricultural resources such as grazing land and water (De Coning et al. 2021), and the variation could trigger conflicts between pastoralists and farmers over water and pasture access (Idris 2018). For instance, South Sudan is vulnerable to climate change and has experienced three successive years of unprecedented flooding (World Food Programme 2021c) and affected more than 700,000 people in 34 counties (Famine Early Warning Systems Network 2020b). The flood destroyed crops, killed livestock, and led to reoccurring localized inter-counties conflicts, consequently leading to loss of livelihood and aggravated food security (De Coning et al. 2021).

Sudan has witnessed climate change from concurrent drought to rainfall variability (Siddig et al. 2020). Besides, there have been 23 mild to extreme drought occurrences between 1970 and 2015 (Elagib et al. 2019). More importantly, the rising temperature in warmer regions poses a threat to the farming of temperate crops such as wheat (Tesfaye 2021). Wheat is a primary staple food in Sudan, it is grown in the central and northern regions of the country (Tesfaye 2021) and technically, there is a need to increase its production to meet the growing population as demand could triple by 2050 (Lizumi et al. 2021). Despite the government's preparedness for warming temperature of 1.5–4.2 °C, it has been estimated that domestic production of wheat will decrease from 16% to 4.5–12.2% (Lizumi et al. 2021) and impact consequences on food security (Asseng et al. 2017). In addition, climate warming would reduce crop yield and cost Sudan an estimated $105.5 billion in GDP between 2018 and 2050 (Siddig et al. 2020). In the same way, Sorghum production, another major staple crop in Sudan, has been underperforming despite the extensification of mechanized farming. Its yield declined since the 1970s from 744.3 kg/ha to an average of 476.6 kg/ha (Elagib et al. 2019).

The agricultural sector is the main source of income and food for the Zimbabwean population (Famine Early Warning Systems Network 2014). Specifically, climate change has presented challenges to crop and livestock farmers in Zimbabwe's rural provinces (Mpambela and Mabvurira 2017). It amplifies food insecurity due to loss of livelihoods, income, and food security (Famine Early Warning Systems Network 2014). For instance, the communities have faced unprecedented drought since the shift in the usual rainfall patterns in the past 5 years (Mukaratirwa et al. 2018), and it has affected the country's major cereal (maize) production yield (Tirivangasi and Nyahunda 2019). Likewise, Botswana's climate is characterized by erratic rainfall punctuated by periods of severe drought, which limits the country's food production capacity (Zhou et al. 2013). Subsequently, the prolonged drought and rainfall between 2015 and 2016 dried up the Gaborone Dam and caused the loss of livestock (Nonjinge 2018). The period was declared the worst vegetation condition index in three decades (Nonjinge 2018).

12.3.5 Migratory Pest

Desert locusts are from the grasshopper family and are considered the most dangerous migratory pest globally (FAO 2020d; United Nations 2020a). Their occurrence is common in Eastern and Southern Africa, although the current upsurge wave in Eastern Africa is the worst in over 25 years in Eritrea, Ethiopia, and Somalia (Showler 2019; FAO 2020d). Recently, they migrated from Yemen to Ethiopia, Kenya, Somalia, Uganda, Sudan, and Tanzania (Ilukor and Gourlay 2021) and destroyed tens of thousands of area units of farmlands and vegetation (United Nations 2020b). The assessment conducted by the Ethiopian government, FAO, and other stakeholders reported that about one million population of Ethiopia had been affected by the Desert Locust through the destruction of cropland and pastures (FAO 2021a). More importantly, Desert Locust plagues can significantly contribute to food insecurity and livelihood (WMO and FAO 2016; Salih et al. 2020) when they attack in extreme numbers (Anderson et al. 2020). Even though no significant impact of Desert locusts on food security has been reported yet, about 14 million people in Ethiopia, Somalia, Kenya, South Sudan, and Uganda facing acute food insecurity are located in the locust-infested regions (Integrated Food Security Phase Classification 2020d). The situation could aggravate the food insecurity situation in these countries.

Outbreaks of desert locusts in Southern Africa, including Angola, Botswana, Zambia, Zimbabwe, and Namibia, since 2020, have compounded the effect of climate change (drought), leading to damage and loss of crops and livestock (IFRC 2021). Brown locust, another migratory pest, spread from South Africa to Botswana and Namibia and caused massive crop loss and pastures (IFRC 2021). Besides, detecting and controlling the early stages of desert locust swarm formation is the most critical step in preventing and controlling the locust plague (Showler et al. 2021). However, other obstacles, such as climate change (Wang et al. 2019), political instability, and insecurity (Anderson et al. 2020; Showler et al. 2021) impede the prevention intervention. For example, the current invasion of locusts in Africa was influenced by heavy rains caused by tropical cyclones in the Arabian Peninsula, which creates an environment for the locust to hatch from eggs, develop, and breed (WMO and FAO 2016; Wang et al. 2021). Additionally, a typical late rainfall in December 2019 initiated the tropical storm that promoted the development and breeding of locusts in the Horn of Africa (Wang et al. 2021).

12.4 Effect of COVID-19 on Food Security in Africa

COVID-19 has spread to every corner of the World, and its effect on food security is still under observation (ZEF and FAO 2020). Although, economists predicted the COVID-19 pandemic would cause the first recession in 25 years in Africa due to low economic growth dwindling to 3.3% in 2020 (Mahler et al. 2020), which could drive up to 40 million people to extreme poverty (Mahler et al. 2020) and food insecurity. The restrictions imposed by the Governments to curtail the spread of COVID-19 were primarily responsible for the economic downturn (International Monetary Fund 2020).

Many West African countries' economies were greatly affected between 2019 and 2021. For instance, the worst economic decline was reported for Cape Verde (5.7% to −14%), Liberia (3% to −3%), Guinea Bissau (4.5% to −2.4%), Sierra Leone (5.5% to −2.2%), Mali (4.8% to −2%), and Nigeria (5.9% to −1.2%) (World Food Programme 2021a). In Burkina Faso, the emergence of COVID-19 exacerbated the food deficit of poor rural and urban households and worsened food security (Zidouemba et al. 2020). Similarly, Nigeria's food insecurity heightened with COVID-19 due to food distribution difficulties, post-harvest losses, increased transportation costs, and food hoarding by marketers (Abdul 2020). Additionally, the effect of COVID-19 on food security was the same for most rural and urban dwellers of Benin, except for families with allotment gardens (Houessou et al. 2021).

This year, limited economic activities during the partial and total lockdown affected many countries' GDP. For example, Kenya's projected GDP growth declined from 5.7% to 1%, whereas Ethiopia fell from 6.2% to 3.2%, and Tanzania and Uganda followed similar trends with 2% and 3.5%, respectively (Deloitte 2021). Trade restrictions reduced food import and export, planting seasons, nomadic pastoralists, and other economic activities during the pandemic. In Libya, an increased number of households had reduced access to subsidized food, electricity, and water during the pandemic between May to November 2019 (World Food Programme 2021b). In contrast, COVID-19 had minimal impact on food security in South Sudan after the imposed restrictions were lifted (Integrated Food Security Phase Classification 2020e). Similarly, no adverse effect of COVID-19 on food security was reported for rural dwellers in Liberia and Malawi, although the lockdown initiated disrupted market activity and caused an income decline among market vendors (Aggarwal et al. 2020).

12.5 Effect of Food Insecurity on Children

The advent of the COVID-19 pandemic adjoined to the already existing food insecurity and survival of young children in Africa, and UNICEF has raised concern about an expected increase in child malnutrition, including wasting and stunting caused by food inflation price, declined home income, changes in availability and affordability of adequate quantity of safe, nutritious food (Akseer et al. 2020). In 2019, before COVID-19, FAO estimated 52 million children were in Africa, with 50 million from the sub-Saharan region (FAO et al. 2020b), and now the influence of COVID-19 could aggravate malnutrition. Countries across the World imposed measures to minimize the spread of COVID-19, disrupted various economic activities, and affected the Gross National Income (GNI) per capita. Research has shown that decreased GNI per capita is associated with child wasting in Africa, and Headey et al. (2020) estimated that there would be an additional 6.7 million children wasting in 2020 compared to the value predicted for 2020 without COVID-19; whereas 21.8% of this projection would be from sub-Saharan Africa. Children are at the forefront of food insecurity because they require high and quality nutrients for growth.

12.6 Sustainable Strategies for Improving Food and Nutrition Security in Africa

Attaining Sustainable Development Goal 2 of Zero Hunger requires identifying the primary drivers and how each driver influences food security in the diverse African contexts. Therefore, Governments are encouraged to adopt the recommended sustainable strategies peculiar to factors driving insecurity in their respective countries.

Governments are recommended to prevent the rise in food prices by preventing food prices volatility, complemented with distributing high density nutrient food varieties directly to low-income earners. The distribution of foods has a higher effect in improving the welfare of households than direct cash transfers (Shittu et al. 2018). In Northern Mali, a study showed that food assistance is a sustainable platform to improve children's development and increase household micro-nutrient consumption (Tranchant et al. 2019). Additionally, food security can be improved by reducing the effect of global shocks on significant imported food prices (Amolegbe et al. 2021), especially rice and milk, by investing in agro-processing and implanting policies to that effect.

Protecting lives and properties is the responsibility of every country leader. Communal clashes and insurgencies influence agricultural output and increase migration and internally displaced persons and refugees. Developing a National/community conflict resolution structure that is sensitive to the origin of the conflict and adopting the resulting localized ex-ante institutional diagnostics would resolve the escalating armed disputes (Schouten et al. 2018).

Governments are recommended to intensify crop diversification for rural farmers to level up the household food consumption score and reduce the prevalence of micronutrient deficiency. Crop diversification has a beneficial influence in attaining food security (Adjimoti and Kwadzo 2018; Mango et al. 2018; Madsen et al. 2021). It involves integrating micronutrient food such as vegetables into staple foods intercropping systems (Rajendran et al. 2017). To further increase food diversity, it is recommended that Government Strategic Grain Reserves be complemented with fruits, vegetables, and animal-sourced foods (International Monetary Fund 2020) and only disbursed to food insecure people (Kalkuhl et al. 2016) during food shortages and high food prices.

Food spends quality time in the food value chain before it gets to the consumer, and during this time, post-harvest losses occur. It is recommended for governments to invest in local storage facilities (International Monetary Fund 2020). Government and private sectors should participate in agricultural products' storage and marketing, facilitating easy access and availability of staple foods during the lean season without causing food price inflation.

The governments are recommended to adopt an outbreak intervention of migratory pests by maintaining the recession phase of the desert locust indefinitely or a proactive intervention of the localized outbreaks from attaining plague status or reactive intervention strategies after the plague status has been reached (Showler 2002). The location and recession areas of desert locusts can be obtained from satellite, the data obtained such as land surface temperature, soil moisture, and precipitation could provide information for the outbreak intervention (Gomez et al. 2020; Escorihuela et al. 2018; Wang et al. 2021).

Sustainable measures are required to mitigate the effect of climate change to reduce its impact on food and nutrition security in Africa. Governments are recommended to establish intensive bioenergy plantations, including monocultures, that could help sequester carbon and replace fossil fuels (von Grebmer et al. 2019). Similarly, the effect of climate warming can be mitigated by providing subsistence farmers with drought- and flood-resistant seeds and subsidized mechanized farming equipment and tools.

12.7 Conclusion

Food insecurity in many African countries has become an eyesore to the continent as many people are juggling between Borderline Food Insecurity (IPC 2) and Acute Food and Livelihood crises (IPC 3), while, in some extreme cases, requiring Humanitarian Emergency (IPC 4) or Famine (IPC 5). Climate change, insecurity, political instability, and migratory pest infestation are the main drivers of food insecurity in Africa. More importantly, achieving SDG 2 by 2030 would be unrealistic without resolving and finding solutions to each region's challenges. However, sustainable strategies such as investing in the agricultural system through sustainable policies; reducing food prices; preventing localized desert locust outbreaks from attaining plague status and counterinsurgency; managing climate; and investing in food assistance in severe, catastrophic food insecurity that best fit each region would bring down food insecurity figures in Africa.

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Chapter 13
Marker-Assisted Selection (MAS): Untapped Potential for Enhancing Food and Nutrition Securities in Sub-Saharan Africa

Wajiha Mu'az Abdullahi, Sanah Abdullahi Mu'az, Abou Togola, Sanusi Gaya Mohammed, Muhammad Lawan Umar, Patrick Obia Ongom, Candidus Echekwu, and Ousmane Boukar

13.1 Introduction

Despite Africa's rich human and natural resources, it is still lagging behind in terms of agricultural development and food security, probably due to slow adoption of modern techniques of crop improvement. As reported by Global Hunger Index, over half of the world's people with food insecurity live in Africa (FSIN 2020). Thus, food production does not match the increasing population in the African region. Increasing food production to meet up the requirement of the bourgeoning population is eminent in order to avoid food crises, especially in sub-Saharan and the dry subhumid parts of the continent. Therefore, to curb food insecurity, reduce poverty, and impact the livelihood of peasant farmers, food production can be increased by harnessing different approaches, including development of new high yielding improved varieties with resilience to major biotic and abiotic constraints as well as increasing output per unit area using good agronomic practices. It is well known that food production is already facing a serious challenge due to population growth, climate change, and economic growth, thus the future food demand cannot be met with the current production trend. Long production period of traditional plant

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breeding that played a role in alleviating hunger in the past is facing rapid changing market, environmental, and climatic conditions. For plant breeding to be more responsive and sustaining its role as principal provider of food security, acceleration of the breeding process is needed (FAO 2020). Due to additional pandemic caused via Covid-19, by 2030, the number of food people facing malnutrition in sub-Saharan Africa (SSA) is anticipated to increase. In other words, significant increase in investment is needed for the region's populace to consume 2100 calories per day per person (FAO 2020).

Deficiency of micronutrient is defined as "hidden hunger," and is attributed to having long-term effect on affected population. As reported by IFPRI (2016), around two billion people are suffering from hidden hunger caused by malnutrition in the world and half are based in Africa. The most vulnerable population affected by this malnutrition are women and children under 5 years, resulting from uneven food distribution within the household, lack of access to quality foods, and infectious diseases incidence (Bailey et al. 2015). To achieve nutritional diet, important protein content with other elements like zinc and iron are needed to be incorporated in legumes crops that are the major source of cheap protein compared to the animal one. Crops with adaptation to wide range of locations, end user preference, including cooking and processing need, can be the focal point of plant breeding in this era. Moreover, in times of swift population growth and climate change, the rate of genetic gain for grain yield potential has to be amplified beyond what is currently achieved in ongoing breeding programs to protect global food security (Voss-Fels et al. 2019), as incorporating new technologies can enhance the efficiency of conventional breeding.

In enriching human diets with more nutritious foods, agricultural improvement is needed while reducing its environmental footprint. Since, after green revolution, present annual yield increment is not more than 1% for major crops in the Africa region, therefore this has to be fast-tracked in order to meet the amplified future demand for plant-based products (Li et al. 2018). Although enhancement of genetic gain by speeding improved cultivars development using biotechnology and new genomic approaches impact the livelihoods of vulnerable farmers in sub-Saharan Africa, its implementation becomes very slow among farmers (Voss-Fels et al. 2019). In the last five decades, improved crop varieties have been developed mainly through traditional breeding, which takes at least one decade per new variety, whereas more reliable methods of crop improvement have evolved over time and are widely used in the developed world like Europe and Asia where examples are tissue culture, genetic engineering, gene editing technology, and Marker-assisted selection (MAS), which is a molecular breeding method using molecular markers as tools in plant breeding program.

For more efficient agriculture, modernization of breeding programs through the application of innovative tools is vital. Recent studies related to integration of molecular markers in African plant breeding have shown that markers play a significant role in breeding optimization, including parental fingerprinting, confirmation of hybridity and early detection of false F_1 plants (Ongom et al. 2021). Quality assurance (QA) and quality control (QC) are required for optimization of a breeding program for increased genetic gain at key stages of the breeding process. Choice of parental line is a vital phase in a breeding program, for a successful hybridization process to associate parental attributes and create differences using molecular markers (Ongom et al. 2021). Since the late 1970s, the application of MAS in crop improvement commenced with the identification of markers dispersed throughout the genome of any species of interest and some of these markers have been used to detect associations with traits of interest (Ojuederie et al. 2011). Since then, there has been rapid evolution in molecular marker technologies from RFLPs, AFLPs, RAPDs, SSR to now popular single nucleotide polymorphism (SNP), which is highly abundant, easy to detect, and automate for high throughput processes (Jiang 2013). Recently, cowpea KASP-based SNP markers have been validated and deployed for hybridity authentication (Ongom et al. 2021) and this is being adopted for routine use across several cowpea-breeding programs in Africa. The Quality control KASP-based markers do not only detect the best parental lines for crossing based on their observed homozygosity and genetic relatedness but also allows screening the resulting F_1 progeny to distinguish between the offspring resulting from cross-pollination and those resulting from self-pollination. In addition, the need to deploy markers in African breeding programs has led to discovery of QTL for several traits across a range of African crops. In Ethiopia five genomic regions (QTLs previously identified to be associated with *Striga* resistance in sorghum variety N13 were fine mapped and deployed in marker assisted backcrossing (Mohamed et al. 2014). The cowpea-breeding program in Nigeria identified three significant QTLs for thrips resistance Fthp28, Fthp87, and Fthp129 were detected on chromosomes 2, 4, and 6 accounting for 24.5, 12.2, and 6.5% of the total phenotypic variation respectively (Sobda et al. 2017).

In cassava, resistance to Cassava Mosaic Disease was identified with six different molecular markers linked to the CMD2 gene in Nigeria (Olasanmi et al. 2021). About 70% of the progenies were identified to be resistant to the disease across the populations with a range of 62–80% using the marker data. The authors concluded that, to fast-track cassava breeding programs in Nigeria, marker-assisted selection can be adopted (Olasanmi et al. 2021). For groundnut (*Arachis hypogea*) in Nigeria, diversity array technology (DArTseq™) was used in 168 African germplasm to identify 3592 biallelic SNP markers and 15,237 dominant silico markers and 25 of these markers were found to be associated with resistance to early leaf spot. The biallelic and dominant markers across the genome shows that chromosomes B04 and A04, in early leaf spot (ELS) disease, caused by *Cercospora arachidicola* S. Hori (Shaibu et al. 2021).

In the coming years, with the global change in consumer activities, food security will be severely met halfway if modern techniques are not quickly deployed in crop breeding programs. Improving crop productivity can be done (i) by dissemination of heritably improved varieties; (ii) through enhancing better management practices. Most of the seed varieties on farmers' shelf at the moment were disseminated from mass projects conducted from International and National research institutes globally, but more efforts are needed to enhance genetic gains and reduce long duration of developing a cultivar by integration of genomics-assisted breeding approaches and rapid generation advancement (Ojiewo et al. 2020). With these, it will be known that incorporation of molecular marker technologies in the breeding process can accelerate improved cultivar development and deployment.

13.2 Marker-Assisted Selection

13.2.1 What It Is and Its Usefulness in Crop Improvement

Marker-assisted Selection (MAS) in plant makes use of DNA markers to indirectly and precisely select and breed individuals with the desired traits, thereby availing food for human generations. This process is very important given that food self-sufficiency cannot be achieved without plant breeding. Additionally, MAS may be defined as the use of molecular markers to improve characters of interest in plants (Chukwu et al. 2019). With molecular markers, selection is possible under any environmental conditions both during the main and off-seasons using screenhouse because traits such as disease/pest resistance and stress tolerance are expressed only in ideal environments (Ruane and Sonnino 2007). Molecular markers are being generated to identify quantitative trait loci (QTL) with effects on some desirable attributes (Boukar et al. 2020). A major benefit of using markers is that homozygosity can be discovered very efficiently, thereby revealing polymorphism in sequencing, thus allowing marker to differentiate more efficiently.

The MAS approach came in to avoid the problems of imprecise phenotyping and lengthy breeding cycles connected with conventional plant breeding from selection of phenotypes towards selection of genes, either directly or indirectly. Molecular markers can be used any time of the season since they are unaffected by the environment, hence they can be regulated in all stages of plant growth (Francia et al. 2005). Therefore, MAS emerged as a strategy for increasing breeding efficiency, precision, and selection gains with respect to phenotypic selection and quantitative genetics (Lande and Thompson 1990). Effective selection of recessive alleles of desired traits in the heterozygous status can be detected using Marker-assisted Breeding (MAB), it saves time and accelerates breeding progress. Using genotypic assays based on molecular markers may be faster, cheaper, and more precise than conventional phenotyping, thus MAB may result in higher efficiency in terms of resources consumption (Andersen 2013).

Advances in DNA sequencing technologies have revolutionized crop breeding and research, opening the "genomics era" of crop improvement. There are cost-efficient geneotyping platforms such as "DNA fingerprint," genotyping by sequence (GBS) which have been developed to enable rapid and accurate high-density fingerprinting (Nkouaya et al. 2020). Interestingly, these resources are ubiquitous, very easy, and cost-efficient in crop genomes, which have contributed to genetic and molecular research.

There is now availability of whole genome sequencing, bringing insight in structural diversity of crops which makes breeding of large plant population possible using MAS (Comar et al. 2012).

However, there is also a challenge of MAS implementation in Africa despite its simplicity (Chukwu et al. 2019; Cobb et al. 2019). Even though quite a number of panes of molecular markers that are closely connected to key crop traits have been identified, successful applied experiences of MAS in Africa are limited (Boukar et al. 2019).

Quite a few types of molecular markers were used in crop plants for genetic diversity studies and to some extent marker-assisted breeding. Some of these include restriction fragment length polymorphisms (RFLP), amplified fragment length polymorphisms (AFLP), random amplified polymorphic sequences (RAPD), cleavable amplified polymorphic sequences (CAPS), single strand conformation polymorphisms (SSCP), and single nucleotide polymorphisms (SNPs) (Mohan et al. 1997; Rafalski 2002). Of these, SNPs have become a marker of choice due to its abundance in the genome and its accuracy. Many breeding programs are increasingly picking up interest in deploying markers for selection as a way of modernizing and accelerating the breeding process. Therefore, selection of genes at the early stage has been made possible, thus saving resources (Blair et al. 2007; Okogbenin et al. 2012; do Carmo et al. 2015). It should be noted that before a molecular marker becomes usable, it takes time for development, moving from (i) creating marker discovery populations which are F_2s, backcross, recombinant inbred lines (RILs) or a diverse collection of lines particularly for marker discovery via genome-wide association study (GWAS); (ii) phenotyping of populations for trait of interest; (iii) genotyping the populations; (iv) finding marker-trait associations and authentication of markers in diverse genetic families. Similarly, selection-using phenotyping is considered challenging for breeders in this region (Cobb et al. 2019). Therefore, to implement marker-assisted breeding, funding is fundamental in sub-Saharan Africa. Impending cultivar development mostly relies on MAS to ensure food and nutritional security in Africa. The establishment of a stage gate system (SGS) will guarantee pellucidity, culpability, and data-driven improvement decisions as this strategy is currently being implemented with the support of Excellence in Breeding (EiB) project implemented by CGIAR and led by CIMMYT. Recently, a stage gate approach has been proposed to streamline the marker/traits discovery in plants (Rabbi et al. 2020). The approach is intended to streamline the movement of materials and information to enable and ensure rapid and efficient movement from identification of trait development through donor and QTL identification to having diagnostic markers with high quality and tested introgression lines available for use as parents in forward breeding processes. These activities and criteria are designed to test the value of the donors/QTLs/genes and the veracity of evidence supporting this value. Similarly, this will provide eventuality wherein if a donor/gene/QTL is not of sufficient value or utility, the work is terminated as soon as this can be determined, reducing waste of effort and resources.

13.2.2 Methods in MAS

With the aid of marker trait associations, identification of regions linked to traits of interest have been identified giving a pointer to underlying phenotypic variation (Garcia-Oliveira et al. 2018). Genetic gain is accelerated through QTL identification as an indirect selection method, where performance of individual in the field is dispensed through the laboratory process. MAS uses molecular markers as tools for selection with high precision and efficiency, which do not involve genetic engineering in the laboratory, as is the case with GMOs. To optimize conservation of genetic resources in gene banks and breeders' collections, genetic redundancy tends to be a challenge, therefore identification of accession has been made possible with SNP markers (Ferguson et al. 2012). Whereas duplication of adopting of improved varieties have also been improved (Turyagyenda et al. 2012; Girma et al. 2017). Giving different names to the same cultivar or landrace by farmers have made identification of specific varieties difficult, but using molecular markers enables the precise assessment, which in turn influences breeding priorities and agricultural policies (Kretzschmar et al. 2018). Guide in parental selection, hybridity test (select true-cross progeny), and to assess the veracity of reputed mapping populations has all been possible with MAS.

The basic steps in a MAS breeding program are as follows: (i) screening the parental lines for particular trait of interest; (ii) developing of mapping population of F_6—F_8; (iii) identification of the molecular markers that are linked to the traits of interest; (iv) genetic linkage maps construction; and (v) marker validation in predicting particular traits

When QTL information is generated, breeders use MAS to develop greater lines with an ideal allele combination originating from parent source. However, genotypic selection helps to identify alleles impacting trait of interest through successive intercrossing of selected parents as selection of best varieties for releasing to farmers is done in recombinant inbred lines population.

At the closest marker and the selection index, the number of target QTL considered have to be adjusted accordingly at different stages. Realistic application of MAS depends on several factors, including the genetic constitution of targeted trait, correlation between molecular markers and target gene, the number of individuals that can be analyzed, and the genetics of relations in which the target gene has to be transferred (Rabbi et al. 2020; Francia et al. 2005).

Consensus genetic map containing 37,372 SNPs mapped to 3280 bins has strengthened cowpea trait detection pipeline, which also helps to increase proficiency and accuracy, thus making the feasibility of using MAS accepted by public, as reported by Boukar et al. (2019).

Several edifying markers associated with quantitative trait loci (QTL) related to required traits of cowpea were generated to improve desirable traits such as *Striga* resistant, drought tolerant, phosphorus use efficient, and bacterial blight and virus resistant in sub-Saharan Africa. Assemblage and preservation of cowpea germplasm, generation of genomic tools for more effective breeding program, and cultivar development are now existing in SSA farmers' fields. The dare of *Striga* to cowpea production especially in the dry grassland agro-ecologies is being effectively contained with the development of varieties that show immunity to this parasitic weed using MAS (Boukar et al. 2020).

In Africa, research programs have started using different types of markers to enhance development of improved varieties. For instance, in the Republic of Niger, MAS, applied in backcross population, was used based on microsatellite markers to transfer *Striga* resistance gene from improved cowpea IT93K-693-2 farmers' adapted cultivars, namely, IT90K-372-1-2, KVx30-309-6G, and TN5-78 (Salifou et al. 2016). In Burkina Faso, four SSR markers were validated for use in breeding for Cowpea Aphid-borne Mosaic Virus (CABMV) (Antoine et al. 2016). Additionally, marker-assisted backcrossing (MABC) using SNP markers was used to introgress drought tolerance, *Striga* and root-knot nematode resistant QTLs into a farmer-preferred widely grown cowpea landrace adapted for intercropping in Burkina Faso (Batieno et al. 2016). In Nigeria, SNP markers were converted into KASP markers and used for parental fingerprinting and authentication of F_1 hybridity in cowpea (Ongom et al. 2021). Also, SNP markers derived using DArT were used to characterize genetic diversity among 255 cowpea accessions from Togo, providing a foundation for genetic improvement of cowpea in Togo (Gbedevi et al. 2021).

In Ethiopian and Ghanaian soybean, QTL mapping has been done for Fusarium wilt using molecular markers (Hartman et al. 2019). In US and Chinese soybean sclerotinia, stem rot, phytophthora root rot, brown stem rot, and asian soybean rust were identified using SSR, AFLP, RAPD, and SNP with 16 QTLs (Guo et al. 2008; Huynh et al. 2010; Li et al. 2010; Wang et al. 2010; Patzoldt et al. 2005).

SSR, STSs, and SCARs markers were used to identify PvPR2, Rsv1, UR-6 genes for resistance to Anthracnose, Halo blight, Fusarium wilt, and Bacterial blight in the United States of America (Shi et al. 2009; Miklas et al. 2014; Kolkman and Kelly 2003; Blair et al. 2007). Additionally, using RFLP and SSR, rice deep roots and rice waxy quality QTLs on chromosomes 1, 2, 7, and 9 were discovered in China and the USA (Shen et al. 2005; Zhou et al. 2003). As reported by Dussle et al. (2002) in Germany using markers SCAR and CAPS, maize Sugarcane mosaic virus (SCMV) Scm1 and Scm2 were finely mapped to maize chromosomes 6 (Scm1) and 3 (Scm2). In addition, cotton fiber strength QTLFS1 was identified using SSR and RAPD (Zhang et al. 2003) in China. These findings demonstrate the growing adoption of molecular marker usage in crop breeding with the implication of enhancing the variety development process.

13.3 Current Breeding Methods in Africa

In developing new varieties used in sub-Saharan Africa, conventional plant breeding is the method commonly used. However, it can no longer sustain the global demand for adequate food to obtain increased crop yield. While traditional breeding approaches have worked well, they can be very time-consuming and sometimes inefficient. One of the meek and effective ways to develop new varieties that are adapted to current climate change in Africa is to shorten the breeding cycles (Atlin et al. 2017). Similarly, the size of crosses differs from one breeding program to the other, the total number hybridization varies between one to thousands. As segregation is occurring, breeders select the best lines after recurrent inbreeding and validation.

Before disseminating a variety to farmers, a high level of homozygosity is needed to ensure it does not segregate further, potentially divulging recessive genetic variants with unfavorable agronomic traits. The rate of triumph in breeding programs depends on the phenology of a line to confirm that there is no passing of bad genetic resource to offspring. Hybrid breeding is one of the most prevalent approaches for outcrossing crop species, where two different inbred lines (extremes) are crossed to generate homozygous F_1 that appear better than both parents (Voss-Fels et al. 2019).

13.3.1 Pure-Line Selection

During the nineteenth century in Sweden, pure-line selection was developed, Johannsen, a Danish biologist (Gardner 1961), explained the genetic basis in 1903. Pure line means a homogenous self-pollinated homozygous plant. Here plants are developed by identification and isolation of single best plant progeny or individual plant selection. In this method, intense selection pressure for resistance to many traits in few available parental lines brings slightly higher genetic diversity for landraces than elite lines in most crops (Gardner 1961).

Better consumer preference is incorporated in varieties that respond better to gene pool of pre-breeding germplasm, where it has merits such as: (i) It tends to be good for isolating the best genotype for high yield with resistance to biotic and abiotic stresses from diverse varieties. (ii) The variety developed by this method is uniform and more attractive than mass selected variety. (iii) This is an easy and cheap method of crop improvement. Pure-line breeding suffers the following challenges: (i) This method can isolate only superior genotypes from the diverse population and thus cannot develop new genotypes. (ii) It is only applicable to self-pollinated species. (iii) The varieties developed by pure-line selection have poor adaptability due to narrow genetic base (Andrus 1963). All the plants of a pure line have identical genotypes; hence, such varieties are more prone to the attack of new disease due to genetic uniformity. Superior varieties have been isolated by pure-line selection from the heterogeneous populations in several self-pollinated crops like wheat, barley, paddy, peanut, chickpea, black-gram, green-gram, linseed, cotton, and tobacco. Pure lines are used either as varieties or as parents in hybridization for development of superior varieties or hybrids in self-pollinated species.

13.3.2 Pedigree Method

The recent trend in breeding is that conservation genetics has established an applicable toolbox to inform species management within the past five decades. The term was first utilized to describe the protocol used by Svalof in Sweden in the late 1890s, whereby required single plants were carefully chosen from heterogeneous landrace populations. Therefore, one of the most long-standing tools available to manage genetics is the pedigree method, which has been extensively adopted to illustrate diversity and exploit evolutionary potential in threatened populations. Moreover, we contended that building and maintaining pedigrees provide an opportunity to strengthen trusted relationships among conservation researchers, practitioners, and indigenous peoples (Galla et al. 2022).

Pedigree record starts from parents, which include description of the ancestors, up to progeny information (Brim 1966). Henceforth, from F_2 generation, selection starts in pedigree method and continues up to subsequent generations (which may extend to grandparent, great-grandparent, or more ancestral generations). Therefore, the method is only applied for self-pollinating crops used for transgressive or combination breeding. Likewise, selection based on physical evaluation in best performing single plant is carried out by keeping track of record from parent–progeny relationships. Thus, it has merits as follows: (i) Maximum amount of selection is achieved with this method. (ii) Selection can be made before inbred lines are fixed, thus saving experimental cost. (iii) Difference in year of planting is an advantage for biotic traits. (iv) There is clear genetic relationships of lines in pedigree method. Its demerits could be as follows: (i) Environment can be a factor for expression of gene of a particular trait-like disease. (ii) It takes longer breeding cycle for cultivar development compared with other methods of breeding.(iii) There must be experienced persons to do the selection. (iv) It requires more land and labor than other breeding methods. Most of self-pollinated crop varieties released in Africa in the previous decades were based on pedigree breeding method. In cowpea, several varieties were developed at IITA using the pedigree method (Murdock et al. 2008; Boukar et al. 2015). Sakha-1 is a newly released cowpea variety from El-Sheikh University in Egypt that proved to be the best genotype for earliness (73.5–73.9 days after sowing), seed yield (573–647 g/m^2), and crude protein content (22.7–24.3%) in both trials. In addition, line 4 with bushy determinate growth habit and high seed quality was derived from pedigree method (Metwally et al. 2021). In Eritrea, five sorghum varieties with early maturity and high grain yield were released using pedigree method (Yohannes et al. 2015)

13.3.3 Polyploidy Method

Possessing more than two complete sets of heritable chromosomes in plants is known as polyploidy. The important feature of polyploidy is having even number sets of chromosomes, with tetraploidy being the most common. However, the importance of polyploidy in plant breeding is proved in the study of eukaryotic genomes, as several of them express the signature of polyploidy ancestry (Tate et al. 2005). Similarly, gene redundancy can be overcome by bestowing long-term evolutionary flexibility, as this has eased the divergence and domestication of plants, even though estimation of relative roles displayed by different types of polyploids during evolution is difficult (Ruprecht et al. 2017). Additionally, advantages of polyploidy are the formations that are indicated by either experiment or theory. Change in genetic and epigenetic function of genome is done during polyploidy. Nuclear cell expansion and increase in the complexity methods are involved in managing and segregating chromosomes during cell division (Tate et al. 2005). Another advantage is activation and suppression of gene expression, which leads to striking evidence of change that comes from the discovery of epigenetic remodeling (Stebbins 1980). In addition, advantages of polyploidy are gain of asexual reproduction by disrupting certain self-incompatibility systems and loss of self-incompatibility, thus allowing self-fertilization.

Some of these can cause instability of the neopolyploids and might be disruptive despite their multiple advantages. Also, gene redundancy can help in the cloaking of recessive alleles by dominant wild-type, which, in gametophytic haploid stage, requires many genes (Stam 1995). Similarly, limitations of polyploidy include the unsettling effects of nuclear, cell expansion, and epigenetic variability that results in non-additive gene regulation.

13.3.4 Mutation Breeding

Impulsive mutations in the plant genome occur naturally, even though the most commonly used mutation breeding method is use of chemicals or radiation to induce random mutations throughout the genome, instead of genetically engineered (targeted) mutation. For example, in a one-hectare wheat field, about 20 billion mutations occur each year (Voss-Fels et al. 2019). Since mutation breeding has been used since the 1930s, accelerating the process of developing different traits for selection has been possible for several traits. Also, it broadens biodiversity using the plant's own genetic resources by mimicking the process of spontaneous mutations (van Harten 1998).

How it works: seeds, cuttings, or the shredded leaf of a plant (tissue) are irradiated or treated with chemicals such as Ethidium bromide or colchicine. Then direct planting in the field is done or cultured in a sterile rooting medium and individual plants picked out and examined for their traits. Ethidium bromide (EB) has been used for induction of CMS in barley (van Harten 1998). Similarly, in *Nigella sativa* plant, 0.025% of colchicine caused mutation that led alterations of morpho-physiological and biochemical traits (Gupta et al. 2021). Currently, new mutagens have emerged, including gamma rays, ion beam, proton beam, electron beam and cosmic radiation, and are being used to create genetic variability for crop improvement (Vikas et al. 2018). Interestingly, in cowpea variety IT-84S-2246D, irradiation with gamma rays from cobalt 60 source and two mutants were selected from 196 Gy populations which induced early maturing, yield, and insect tolerance (Adekola and Oluleye 2007). Also, in Bangladesh Institute of Nuclear Agriculture (BINA), a soybean mutant variety, "Binasoybean-6," from line SBM-22 was found to be higher yielding as well as tolerant to yellow mosaic (YM) and insects. Greater seed yield in the mutants discovered that induced mutations could successfully be employed to create genetic variations in soybean (Malek et al. 2022). The following are the advantages of mutation breeding: (a) New varieties can be developed quickly and easily with little resources. (b) Oligogenic characters are best for this method of breeding. Despite its numerous advantages, it could have some limitations such as: (a) The method is uncertain and unpredictable. (b) There is rareness in its usefulness which is predominantly recessive. (c) Mutants can have strong negative pleiotropic effects on other traits. (d) Some of the chemicals have a high risk on the health of the user.

13.4 Modern Crop Breeding Techniques

13.4.1 Micro Propagation

Vegetative production of plants artificially is known as micro propagation through tissue culture or cell culture techniques. Plants can be produced both asexually, that is, via vegetative parts' multiplication or sexually by seed production. Genetic replicas of plants that are referred to as clonal propagation are multiplied asexually (George et al. 2008). Several methods are available such as meristem culture, callus culture, suspension culture, embryo culture, and protoplast culture. In plant, tissue culture under aseptic condition plant material is grown in a medium to produce new platelets. Interestingly, this process is beneficial for developing countries looking to increase crop yield, where individuals and companies can grow plants in mass with small space. Successful application of clonal propagation to the following has been done in some crops like potato, apple, and many other ornamental plants (Pierik 1991).

Success of plant tissue culture depends on sterile environment and growing medium. Once the new plants have been successfully propagated, they are transferred into a more natural environment after hardening. This process is usually much quicker and faster, giving room for commercial producers to decrease the cost of labor. One more useful in breeding process is tissue culture, where genetic variability is created to increase the number of desirable germplasms available to the plant breeder (Brown and Thorpe 1995). Undergoing barriers of hybridization such as pre-zygotic problems can be corrected using this method by creating a wide range of genetic variation (Brown and Thorpe 1995). In Uganda, banana free from diseases is widely grown using the tissue culture method (Mulugo et al. 2020).

Another means where plants can be grown asexually is seed culture, where seeds are directly grown uniformly and much faster, for example, in wild cowpea seeds, which have hard seed coat. Evert (2006) reported meristamatic culture where cells grow into an organ and later a whole plant, which are free from viruses and other microorganisms like in banana. In the same way, embryos present in seeds can be used as explants to grow viable plants, where mature or immature embryos from seeds are extracted and supplied with necessary culture medium, which will later develop into shoot or root system of that plant. This is also called embryo rescue method and is practiced in sweet corn. An additional method is callus culture, where unorganized plant cells are extracted and cultured on a suitable medium, whereas anther culture produces haploid plants because the anther contains only the male stamen, which in turn reduces breeding cycle, with Datura and African violet plants being clear examples of this breeding method (Germana 2011). Cells that are not normally involved in the development of embryos are used to make somatic embryogenesis in coffee plants. Also, cell studies and how biochemical reactions occur within a cell are done in protoplast culture, especially arabidopsis, lettuce, and rice. Where an organ such as shoot, root, leaf, and flower are isolated for an in vitro growth, it is called organ culture, which helps to provide information on patterns of growth, differentiation as well as development (Phillips and Garda 2019).

13.4.2 Genetic Engineering

Inserting of genes to plant whole genome is known as genetic engineering (GE), as the first genetically engineered plants were grown commercially in 1996, herbicide and insect resistance are the most common genetically engineered in plants (Mackelprang and Lemaux 2020). Effective transformation and regeneration are key in GE method, where *Agrobacterium*-mediated transformation has always been the method of choice (Khatun et al. 2022). Genetic engineering provides addition, removal, and fine-tuning of specific genes of interest with minimal undesired changes to the rest of the crop genome. Compared to conventional breeding, desired agronomic traits can be generated within a few generations (Dong and Ronald 2019). To enhance nutritional, food safety, and security, GE can play an essential role; better yield has been achieved with this tool (Tripathi et al. 2020). Interestingly, in apple, CRISPR/Cas9 DIPM1, DIPM2, DIPM4 Knockout NHEJ Agrobacterium-mediated transformation resistance to fire blight disease has been achieved (Malnoy et al. 2016). Additionally, in citrus CRISPR/Cas9 CsLOBI knock out NHEJ has been used using Agrobacterium-mediated transformation resistance to citrus canker (Jia et al. 2017). In Nigeria, Transgenic cowpea with Bt gene cry1Ab showing resistance to M. *vitrata* has been released. Manipulating DNA from an unrelated plant or animal and inserting it into the DNA of another organism has been in practice with modern day breeding (Mittler and Blumwald 2010). There are also several advantages that must be considered. (i) Production of better food products has been made possible. (ii) It is faster and has better yield and disease resistance. (iii) It allows specific traits to be developed for plants and animals; thus, it could have disadvantages, namely: (i) Abusing the technology is easy. (ii) It creates difficult legal liabilities with unintended consequences. (iii) Diversity is limited in crops. (iv) It only prolongs the resilience effect, sometimes with negative consequences on other species. (v) It can introduce new diseases.

13.4.3 Gene Editing

One of the most popular technologies in plants of this decade is genome editing, where a functional genomics in MB aid crop improvement. Clustered regularly interspaced palindromic repeats (CRISPR) genome editing is currently the furthermost method due to its easiness, competence, specificity, multiplexing, and adaptiveness (Atkins and Voytas 2020). There is a lot of potential for using genome editing in plant breeding because of its efficiency and precision. As reported by Boukar et al. (2020) in cowpea, genome editing can be a powerful tool for developing improved varieties with durable resistance to pests and diseases. It also shortens breeding cycle as novel plant varieties could be used for crop production or as prebreeding materials.

CRISPR gene editing method, guide RNA directs the Cas9 enzyme to the target DNA site and cuts the DNA where activation and deactivation of alleles in a target gene produce disease resistance or drought tolerance crops (Liang et al. 2017). At this stage, adoption is needed, as many countries have deployed strict legal frameworks due to projected consequences of not accepting genetically modified crops. CRISPR/Cas9-based genome editing is mainly driven by IITA, in partnership with a handful of national research organizations. Funding and appropriate legal structure to guide this technology is still making Africa lag in using gene-editing technology (Tripathi et al. 2020). Developing disease-resistant varieties in banana has been achieved with CRISPR/Cas9-based genome editing (Tripathi et al. 2020). Deactivation of integrated endogenous banana streak virus (eBSV), dsDNA badna virus, integrated into the B genome of plantain (AAB) gene editing, has been used to overcome banana and plantain diseases in hybrids (Nadakuduti et al. 2018). Also, in potato, CRISPR/Cas9 Coilin Knockout NHEJ Biolistic transformation increased resistance to Potato virus (Makhotenko et al. 2019). Furthermore, biosafety considerations remain a public concern as capturing consumer approval and trust is key to the effective implementation of this new breeding technique and to harness its full potential (Table 13.1).

Table 13.1 Summary of regulatory approaches in different countries for genetically modified crops

Country	Current regulatory approach	References
Argentina	GE with no foreign gene is not subjected to GMO regulation	Lema (2019)
Australia	According to Australian Office of the Gene Technology Transfer, GE crops with no foreign gene integration (SDN1) are not regulated as GMOs	OGTR (2018)
Brazil	Regulate GE products on a case-by-case basis and exempt it when there is no transgene insertion	OECD (2019)
Canada	Canada's regulatory process is based on novelty. If the technology creates a novel product, it requires additional regulatory insight	Smyth (2017)
Chile	Regulate GE products on a case-by-case basis and exempt it when there is no transgene insertion	OECD (2019)
European Union	The European Court of Justice ruled that organisms developed using GE are considered GMOs	Wight (2018)
India	India has not issued any formal guidance for regulating GE products. It does not consider GE to be GMOs, so GE products are reviewed at State level.	OECD (2019)
Japan	In Japan, varieties developed using GE with no new DNA are not GMOs	
Kenya	Guidelines for regulating GE products are under development	
Nigeria	Biosafety agencies are drafting guidelines on GE	Enviro news (2019)
United State of America	No biosafety oversight for GE application, if there is no genetic element from pathogenic species or pesticidal traits introduced	Razzaq et al. (2019)

GE genome editing, *GMO* genetically modified crops, *SDN* site directed nucleases

13.4.4 Speed Breeding Method

Alternatively, "speed breeding," developed by Dr. Lee Hickey and colleagues, provides a non-GM route to rapidly introduce or stack new trait variation. It speeds the cycle of generation up to six per year by using controlled environment and extended photoperiods in one or two fields. Whereas development of inbred lines from a cross can speed up just as in doubled haploid technology, positive modern technologies such as speed breeding have been proven to assist the development of improved crop varieties (Watson et al. 2018).

Genomic Selection

Genomic selection (GS) or genomic estimation can complement MAS; as MAS uses markers for specific traits, while GS is being used for traits, GS relies on predicting the genomic estimated breeding values (GEBV) of an individual using a trait-specific model built by concurrently suitable data provided by thousands of molecular markers spread all through the genome (Meuwissen and Goddard 2010). For using GS in plant breeding, there are great expectations because it surely shortens breeding cycle, increases genetic gain because it has enormous potential to be used for accurate selection of complex traits such as yield (Heffner et al. 2010).

This success has been attributed to their high-to-moderate heritability, large-effect QTLs, and low genotype-environment interaction (Torres et al. 2019; Yonis et al. 2020). Additionally, GS is applicable for complex traits with low heritability and late traits during breeding cycle (de Oliveira et al. 2018). Poor prediction of model across population has been a limitation for GS, and for every breeding cycle, re-calibration is needed, which also becomes a drawback in utilizing data from different locations and breeding programs (Somo and Jannink 2020; Wolfe et al. 2017). Integrating biological knowledge in GS could make it to be more robust with the creation of dual-purpose population; new cultivar development pipelines can be practical in ensuring data collected are closely associated to the novel clones with continuously updating the training model (Santantonio et al. 2020). Shortening of breeding cycle has been achieved in rice, wheat, and maize with results worth encouraging for varietal development. Still befrore implementing GDS its applicability and efficieny need to be evaluated (Heffner et al. 2010; Rajsic et al. 2016).

Torres et al. (2019) higlighted good progress in choosing clones of cassava for yield traits using genomic selection. Yonis et al. (2020) evaluated genomic prediction for root size and shape based on root traits extracted from digital images in cassava.

Shuttle Breeding

International Maize and Wheat Improvement Center's (CIMMYT) developed shuttle breeding for wheat breeding program, and was popularized by Nobel laureate Dr. Norman Borlaug. Alternation of field location enables addition of extra generation to be advanced each year. The wheat shuttle-breeding program at CIMMYT used two different field locations in Mexico, which permitted off-season breeding activities. Contrasting field location due to variation in disease and environmental condition improves selection efficiency of target trait (Ortiz et al. 2007). In rice, shuttle-breeding program was initiated in 1982 (Mackill et al. 2013). Intellectual property regulations and protection of national germplasm have been one of the challenges of transporting/exporting seeds, but private sectors use advance off-season planting.

Rapid Generation Advance (RGA)

For decades, cereal breeding program has been using rapid generation advance (RGA), which is also referred to as single seed descent (SSD), and is an alternative breeding method. Improvising growth conditions permit the line fixation to be completed quickly so that traits such as flowering and seed germination can be induced faster than under normal growing season. Some of the advantages of RGA compared to other breeding methods are low resources accumulation, it is faster and quicker (Collard et al. 2017; Fahim et al. 1998).

13.5 Opportunities of MAS in Sub-Saharan Africa

In African continent, key aspect in improving the production and success of breeding is the use of technological development. Breeding in African institutions have mainly been characterized by germplasms, assessment of genetic diversity, identification of new variety, linkage mapping, and mapping of QTL. CGIAR centers such as IITA, ICRISAT, CIMMY, IRRI, and partners have improved many traits in multiple crops by using molecular markers, even though the reliability and utilization is still in progress across regions. A large number of accessions can be utilized by using shared genotyping services, which can also reduce the cost of this technology. Introgression of QTLs in adapted cultivar for additive effects, dominance, and epistatic could be possible in this continent by using MAS. Knowledge-sharing between scientists, regulators, and policymakers can help in developing guidelines for the public.

Lack of a fully functional laboratory in African National Agricultural Research Systems (NARS) with skilled technical staff has been a bottleneck for the implementation of MAS in Africa, whereas advance research innovation ability and funding are imperative for agricultural revolution. Additionally, accessibility to consumables and state-of-the-art equipment has been challenging for NARS in this cycle (Tester and Langridge 2010). Because new breeding methods need to be embraced to release varieties that can be adapted to climate change in African region, similarly distinctiveness, uniformity, and stability (DUS) could be applied by commercial seed companies to develop new cultivars resilient to climate hazard in Africa (Patella et al. 2019).

Genome-wide association studies (GWAS) is increasingly popular, with funding cutting across collaborative projects involving CGIAR and NARS centers, which has led to the development of trait-linked markers (Rabbi et al. 2020). Excellence in Breeding (EiB) is a project capable of removing the hurdles currently faced by breeding programs in Africa, thereby mainstreaming the use of genotyping data. With fund from Gates Foundation, which offers small breeding programs with high quality genotyping services, including low-density (Kompetitive allele-specific PCR [KASP]) and mid-density (DArTAg) genotyping to ensure proper implantation of MAS by NARS centers. IITA and NARS partners in Uganda, Tanzania, and Nigeria are taking advantage of accession identification, quality control, and markers validation (Wolfe et al. 2017; Kayondo et al. 2018; Somo and Jannink 2020). GBS for genomic selection is now exchanged with mid-density genotyping, DArTAg, a target genotyping provided by Diversity Arrays, whereas digitalized data capturing has made things faster and minimize error, as its usage is in full implementation by institutes like IITA and some NARS partners using Breeding Management System (BMS).

With this advancement, bigger and deeper impact of implementing best practices and procedures will definitely increase breeding efficiency in this continent. Breeding network form between CGIAR and NARS has given much opportunity for capacity building of upcoming breeders from within and outside of the continent, because MAS needs technical expertise. Collaboration has achieved national sustainability by the breeding programs. In order to adapt and sustain, MB communities of practice has been developed for many crops where both breeders and related value chains share resources and ideas to look for ways to tackle climate change in envisioning food and nutritional security (Sonnino et al. 2007).

13.6 Biosafety Concerns in MAS Techniques

Collaboration between government and National biosafety committees plays an important role in regulatory decisions in climate change solutions. However, MAS is not always beneficial, so careful analysis of factors involved is important when choosing a technology relative to the conventional breeding programs. In producing safe and nutritious food, standard biosafety laws to regulate agricultural biotechnology need to be in place (Ojuederie et al. 2011). Apart from economic analysis, environmental and end user health risk assessment should be done in order to make MAS safe for African people. Therefore, keeping sustainability of agricultural ecosystem in mind is priority when designing framework of a precautionary approach (Delmer 2005).

13.7 Data Management and Analysis

For effective breeding process, data reliability and availability is paramount, so also access to recent tools for precise management as a key area of breeding climate-smart crops. Virtual platforms such as BMS, open access have been an opportunity to improve data management in plant breeding (Thompson et al. 2020). Access to weather information in database like Kukua has modernized breeding technology, thus enabling germplasm information in track record practicable. A globally sustainable system has been developed for genome sequencing using technological advancement of data revolution. Even though correlation of data and breeding evolution is reasonable over the decades, success of modern breeding is solely dependent on harmonization of multidimensional data and facilitation of resources for community integration (Thompson et al. 2020).

Machine learning has been a novel research area in agriculture, where predicting of important traits is taking place using drones, robots, computers, smartphones, tablets, etc., to facilitate data collection with coherence and accuracy both in the field and laboratory. Imaging technology plays a good role in precision agriculture, with impeccable data interpretation using machine-learning-processor processing (Niazian and Niedbała 2020). Robust statistical tools and innovative platforms are necessary in order to effectively interpret the large amounts of data generated in the changes in climate. Furthermore, tracking of samples, storage of both phenotypic and genotypic information to guide data utilization in plant breeding is critical

(Santantonio et al. 2020). Additionally, open access repository database such as Breeding Management System (BMS) has been established to unify information access and support breeding programs (Fernandez-Pozo et al. 2015; Trushar Shah 2019). The smartphone-based diagnostic system (NURU-AI) is being advanced to provide remote analysis by vulnerable farmers in Africa for real-time prediction of the state of crop health (Nkouaya et al. 2020).

13.8 Conclusion

Plant breeding is a critical contrivance to eliminate food insecurity in Africa, with the emergence of new pests and diseases; for change in consumer preference, global partnership is needed between the government and the private sector within plant breeders. It is well known that climate change tends to worsen with biotic and abiotic stresses in African regions, hence for food sufficiency to be achieved, conventional and biotechnology approaches need to be embraced by sub-Saharan Africa plant breeders in order to feed the escalating population in future. Since enough diversity has been established with the available genetic resources on this continent, the adoption of new approaches is needed in order to identify necessary QTLs for important traits and embrace multilocational trials.

It is therefore imperative to embrace high throughput and precise phenotyping approaches because there is urgent need to translate knowledge acquired into practical use in order to curtail hunger in sub-Saharan Africa. Well-defined metrics is needed in order to establish and invest in advance breeding system. There also has to be constant monitoring of genetic gain and quality traits, which were given less priority in the last decades, with translating biochemical parameters into qualitative traits. Furthermore, immediate implementation of these methods by NARS is needed in order to disseminate these advancements within regional network of breeders and related specialty. Last but not least, policymakers should support the scientists with more friendly policies for the adoption and implementation of modern technologies that will facilitate crop improvement in the region. This will significantly improve food and nutrition securities in the region. With the current planned molecular research at the international Institute of Tropical Agriculture (IITA), Nigeria is focused on mining genomic resources developed over time to identify useful alleles that can be deployed in breeding programs. Work is underway to utilize geographical information (GI) data for IITA gene bank accessions of cowpea and cassava to conduct GWAS study, which will allow exploitation of drought, and heat-tolerant alleles in these crops for deployment in marker-assisted breeding. This is expected to accelerate development of marker-assisted selection platforms for these crops that will be adopted across CGIAR centers and the national research programs in Africa.

Authors' Contribution AWM apprehended this review and drafted the manuscript. OB and SG edited the document. MSA and AT conscripted a section of the

document. OPO and UML provided critical edits. All authors did approval of submission and contribution.

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Chapter 14
Harnessing the Opportunities for Sustainable Small-Scale Rural Farming Towards Attaining Food Security in Southern Africa

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14.1 Introduction

Agriculture has been the primary source of food for humans, fodder for livestock, and revenue for nations since the beginning of humanity. Small-scale farmers in developing nations play an important role in ensuring food security and increasing national income (Dioula et al. 2013). The contribution of agriculture to national gross domestic product (GDP) in industrialised countries has been reduced significantly because of industrialisation; nonetheless, agriculture remains critical for the provision of food. In developing countries, agriculture remains key to meet increased demand for food due to population growth. Thus, livestock production has increased rapidly in developing countries (Food and Agriculture Organization (FAO) 2017). FAO (2017) reports that demand for food and other agricultural products is projected to increase by 50% between 2012 and 2050, but the demand will undergo structural changes due to population growth, urbanisation, and per capita increases in income.

Agricultural production is extensive, and it encompasses forestry, staple food crops, livestock, engineering, economics, and soil management, among other things

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(FAO 2017; Pawlak and Kołodziejczak 2020). Agriculture includes the processing and marketing of products, which are both recognised as part of the industry. For this reason, agriculture, according to Winter et al. (2017), can be defined as the production of agricultural products as well as their processing, promotion, and distribution. On the other hand, small-scale farmers are not a homogenous group and a consensus definition still does not exist (FAO 2017; Foresight4Food 2020), thus, the small-scale farming definition must be contextualised. At times, they are interchangeably called smallholder farmers. Small-scale farmers are characterised and defined based on market access, farm size, level of production, or economic scale of a farming operation, production goal, financial assets, and level of education; and these attributes vary widely. Thus, small-scale agriculture is defined in different ways and varies with countries. The most widely used definition refers to those farms of less than 2.0 hectares (International Fund for Agricultural Development (IFAD) 2013). However, in common parlance, the term is often used to refer to any farmer who is not large scale and/or not very financially well off.

Disaggregating small-scale farmers is critical to understanding their role in food systems and to developing appropriately targeted interventions. Unfortunately, the only disaggregated way that exists is in relation to farm size. It is claimed that small-scale farmers produce 70% of food consumed by people living in low-middle-income countries (Wytske 2019; Foresight4Food 2020). However, this is complex because only a small number of small-scale farmers operating on a 'large' scale significantly contributes to small-scale agriculture production (Herrero et al. 2017; Ricciardi et al. 2018). The majority of these farmers produce for their own food and nutrition security as well as for localised markets, rather than to meet the expanding demands of urbanised populations. This has significant consequences for issues such as where to direct resources to satisfy rising food demand and how to alleviate rural poverty and food insecurity that are connected with low agricultural production and revenue.

For agriculture to achieve its full potential and reap its benefits, the relevance of value chains, the requirement for information asymmetry within those value chains, and the collectiveness of the various multi-stakeholder stakeholders are all important considerations to bear in mind (Trienekens 2011). As such, agriculture is the economic system's backbone in any given country. Agriculture, in addition to producing food and raw materials, is essential in a variety of other ways. It serves as a source of employment, hence lowering the high rate of unemployment in low-income countries, which is caused by the rapidly expanding population (Winter et al. 2017). As a result, economic development occurs as the level of national income as well as the standard of life of the population rises.

The fast rate of development in the agriculture sector offers a progressive outlook as well as increased motivation for sustainable human development (FAO 2018). Similarly, it is significant to internal and international trade's further contribution to the national gross domestic product (GDP), mainly in developing countries. Intrinsically, Huma (2020) stated that national economic development relies on agricultural growth rate. Agriculture is a source of livelihood and close to three quarters (70%) of people earn a living through agriculture (Bacco et al. 2019). It also contributes to the supplies of food and fodder, raw materials for major industries focused on edible and non-edible products (Graddy-Lovelace 2020). This is clear evidence of the importance of agriculture to livelihoods, income, and food security. If well managed, this can lead to significant improvement in national economies and food security in developing countries. This is because a stable agricultural sector ensures a nation of food security.

There is clear evidence that agriculture is a pillar for local economies and food security in the region. Despite urbanisation and industrialisation, small-scale agriculture remains a key driver and contributor to GDP and food provisions (FAO 2017). The majority of small-scale farmers in Southern Africa rely on agriculture for a living (Wytske 2019). It is, therefore, justified for the government to consider agriculture for local economic development. However, small-scale farmers are not homogenous, therefore they need to be contextualised per countries to enable devising and providing targeted interventions and appropriate support to ensure transformation and sustainability. This is also influenced by the fact that small-scale agriculture is defined differently for the countries within the region. Nevertheless, the government still has to provide necessary support to small-scale farmers for them to attain maximum level of contribution towards local economies, food security for the rapidly increasing population, reduction of unemployment, and other developmental agenda (Pawlak and Kołodziejczak 2020).

South Africa, for instance, as one of the countries in Southern Africa, is battling with poverty, underdevelopment, and inequality, further exacerbated by food insecurity (Beaubien 2018). On the other hand, agriculture is the major economic driver in some provinces of South Africa, alongside tourism and mining. Therefore, agriculture has been identified as one of the critical pillars in the National Development Plan (NDP) Vision 2030 to redress these challenges and enhance food security. The NDP 2030 was informed by the UN Sustainable Development Goals (SDGs) and specifically the SDG number 2 that seeks to halve poverty and underdevelopment by 2030 through the zero hunger challenges, and so agriculture (small-scale farming) in developing economies is key to attaining this (Dioula et al. 2013; Winter et al. 2017*)*. Although there have been some huge strides to reduce hunger and the number of undernourished people the world over, there is still more to be done. The report on the state of food insecurity across the globe highlights that the number of hungry people in the world remains unacceptably high with almost 870 million people chronically undernourished according to the estimates of International Fund for Agricultural Development (FAO 2012; IFAD 2012), and World Food Programme (WFP 2021), with higher indices recorded in the developing countries (United Nations (UN) 2012).

Small-scale food production is one of the key pathways to attaining sustainable agriculture. Small-scale farmers are vital to Africa's food and nutrition security (Dioula et al. 2013). They are economically viable in food systems and currently generate most food for the poor countries. Appropriate interventions, national and international policy suggestions have been applied in Africa to improve small-scale farmers' productivity and impact food nutrition security (Dioula et al. 2013). Food nutrition security is achieved when food security is paired with a clean environment, adequate health services, and good care and feeding practices for all household members (UNSCN 2017). SDGs and food security are intertwined. So, the SDGs inform the NDP sections on food security. There is a dearth of comprehensive land policy, support, training, and investment for farmers (Dioula et al. 2013; Tjale et al. 2020). The COVID-19 Pandemic began in 2020. According to Shutske (2020), COVID-19 will likely negatively affect agriculture and the broader economy. The imposition of travel restrictions hampered the movement of raw materials and finished agricultural items locally, nationally, and internationally (Shutske 2020). Seretto (2021) states that movement limitations hindered the transfer of manpower, equipment, and materials between farms. As a result, millions of farmers lost jobs and income. This calls for multi-stakeholder involvement and support. Despite all these challenges, the contribution of small-scale farmers to global food production is significant. They supply up to 50% of the world's cereal, 60% of the world's meat, and 75% of the world's dairy production (Kremen et al. 2012), and both urban and rural dwellers in developing countries heavily rely on them for food supply.

The link between agriculture and nutrition security is supported by conceptual frameworks that show pathways in which agriculture is influencing food and nutrition security (Fan 2011; Dorward 2013; Gillespie and van den Bold 2017). These frameworks are built upon the widely known United Nations Children's Fund (UNICEF)'s framework that identifies three main determinants of food nutrition: availability and access to food; optimal quality of feeding and caring practices; and a healthy environment and adequate access to health care services. This framework paves the way for communication between multiple stakeholders and sectors, which is key in small-scale agriculture in Africa (Huma 2020).

The world triple challenge of food production, nutrition security, and environmental concerns forces stakeholders for the agricultural community to focus on sustainable development and sustainable agriculture (Boakye 2018; Singh and Nath 2020). Sustainability is a development that, "meets the needs of the present without compromising the ability of future generations to meet their own needs", all these being done in a socially acceptable, economically efficient, and environmentally friendly manner (Mensah 2019). Likewise, farming approaches that are environmentally friendly and that allow the production of crops or livestock without damage to the farm as an ecosystem, including effects on soil, water supplies, biodiversity, or other surrounding natural resources become very pertinent. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD 2009) states that there are close linkages between food security and sustainable agriculture. These linkages place smallholder farmers at the heart of sustainable food and nutrition security and foster inclusive rural development and transformation (IFAD 2016).

Small-scale farming has huge potential to contribute to both food security and sustainable agriculture (Hendriks et al. 2019). As a result, some measures called for include encouraging homestead food production, micronutrient-dense crop types, and environmentally friendly agricultural practices such as agroecology (de Schutter 2010; Hendriks et al. 2019). Agroecology is a set of agricultural practices that seek ways to enhance agricultural systems by mimicking natural processes, thus creating beneficial biological interactions and synergies among the components of the agro-ecosystem (de Schutter 2010). The core principles of agroecology include recycling nutrients and energy on the farm, rather than introducing external inputs; integrating crops and livestock; diversifying species and genetic resources in agroecosystems over time and space; and focusing on interactions and productivity across the agricultural system, rather than focusing on individual species (Duff et al. 2022). Other promoted strategies are women empowerment, improved post-harvest handling and the do-no-harm principle.

Interventions to improve small-scale agriculture are a necessity given that it is the main employment sector for the poor. It employs 76.3% of the extreme and 60.7% of the moderate poor in Africa (Castañeda et al. 2018). Most of this group tend to be subsistence- or semi-subsistence-oriented and face significant barriers to entering higher value agricultural activities. These are some of the first issues to consider in the intervention strategies if indeed agriculture is to be sustained for subsequent and significant contribution to food security in Africa. There could be a need as well to determine which categories of farmers will be able to respond to future food demands, which categories of farmers will be more vulnerable to climate change, and which resources decline. Response to these issues is key in targeting appropriate farmers and devising appropriate strategies for the farmers to reach their full potential and contribute significantly to food security in Southern Africa. Therefore, this chapter focused on a detailed perspective and importance of small-scale farming in Southern Africa, challenges faced and associated opportunities available or that can be devised to avert the challenges. The methodology used to develop this work was compressively discussed. Presented herein as well are the practical and policy implications and science communication to promote sustained agriculture and, subsequently, food security in Africa.

14.2 Methodology

Research methodology is defined as a contextual framework that shows a coherent and logical scheme based on beliefs, views, and values that guides the research process (Gray and Malins 2016). In this study, a qualitative research approach was used in which secondary data were collected from secondary sources such as published books, newspapers, reports, and articles. Desktop data collection technique was employed to gather the necessary data. Mills (2019) describes the qualitative research approach as the collection and analysis of non-numerical data such as texts, video, or audio, hence case study research is employed. As such, the study used published literature (second-hand data) from published books, journals, and online portals. Thus, secondary data collection is usually associated with an in-depth understanding of issues in its real-life context (Gray and Malins 2016). In this study, a seven-step model, described in Fig. 14.1, was used.

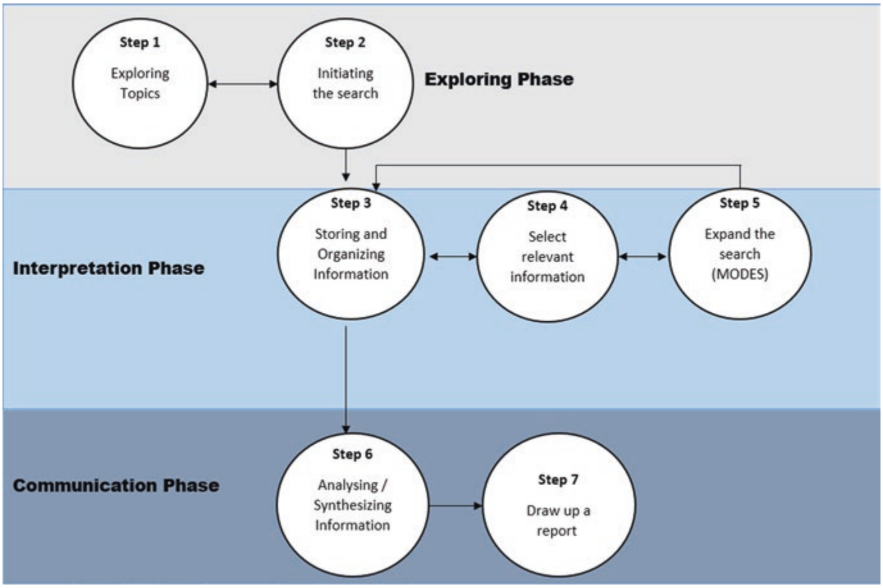

Fig. 14.1 The seven-step model for a comprehensive review of literature. (Source: Sagepub (2018))

14.2.1 Phase One: Exploring and Information Search

Exploring and information search is part of collaborative information seeking (CIS) (Shah and Gonzalez-Ibanez 2019). The CIS process is regarded as the best method for exploring and searching for information by a group of people. There are two steps usually followed when CIS is used in review papers, which extend to collaborative information synthesis by group members (Shah 2018). These steps are exploring topics and initiating the search and are described in the following subsections.

Step One: Exploring Topics

Exploring topics entails the process of brainstorming on the ideas, which are in line with the topics investigated (Shah and Gonzalez-Ibanez 2019). The process includes a deep investigation of the topics, which intends to guide the information to be used in the study. This process also involved deep enquiry of the existing topics to discover information about the desired topics (Li et al. 2018). Thus, exploring topics is done in a way that words included in the main topics and subtopics should have equal weight, hence developing a straightforward and effective topic. As such, topics such as the importance of agriculture in rural development, levels of productions for small-scale farming, and challenges faced are some of the topics explored in the first step. All relevant topics from journals, reports, and online newspapers were explored and the ideas linked to the study were recorded for deeper enquiry. Once all topics were recorded, step two was adopted.

Step Two: Initiating the Search

Initiating the search entails exploring literature guided by the chosen topics and themes in a study (Jocius and Shealy 2017). Usually, several strategies such as basic search strategies, online searching techniques, full-text electronic journals, and databases search are some of the methods which can be used. Considering these strategies, the commonly used methods are Boolean Logic, parenthesis, phrase searching, truncation, wildcards, and field searching (Gusenbauer and Hathaway 2019). As such, the phrase search, which allows users to search for documents containing an exact sentence or phrase, was used in this study. To this end, initial search entails rigorous information search from online platforms, books, journals, and newspapers ensuring that relevant information for constructive arguments is guaranteed. Considering step two, explored literature gave a synopsis of areas such as opportunities for agriculture in Africa and solutions to the identified challenges.

14.2.2 Phase Two: Information Interpretation

Information interpretation refers to the implementation of the processes through which the gathered material is reviewed for arriving at an informed conclusion (Braithwaite et al. 2018). This process also means assigning meaning to the information, hence determining common themes and implications (Gusenbauer and Hathaway 2019). This phase has three steps, namely, storing and organising information, selecting relevant information, and expanding the search if more information is needed. For instance, gathered information for challenges faced in this sector was subdivided into four distinct sections, namely, scarcity of natural resources and competition for the scarce resource, climate change effects, and soil and water pollution. Thus, information interpretation paved the way to storing and organisation of information for better reading.

Step Three: Storing and Organisation of Information

Information storing and organisation entails the process of knowing the data, hence the ability to understand the issues investigated thoroughly. Once the data is well organised, there are several basic methods of storing information, namely, document-retrieval systems, database systems, and reference-retrieval systems (Vetro et al. 2020). To use phrase search, database systems and a document-retrieval system were rigorously used. Document-retrieval systems entail storing entire documents, which would be retrieved using the titles or certain keywords while a database system allows the application that permits retrieval and manages data systematically (Vetro et al. 2020). This method permits full text searching, hence allowing retrieval of information based on any keyword used. Subsequently, database systems are storing the information as a series of separate records using names, addresses, or years of publication (Azeroual et al. 2018). In this study, information was stored using records' names and paying attention to addresses of the year and this guide on keeping up to date information. Furthermore, reference-retrieval systems entail storing references to documents rather than using the document information itself.

Step Four: Select Relevant Information

Selecting relevant information is an important step as it identifies sources with credible data. Vetro et al. (2020) stated that selecting relevant information requires an understanding of depth, objectivity, and the purpose of the selected information. Understanding the selected information may create complete reliable data and skills to connect it to the topic investigated. Thus, this step is usually associated with knowing the purpose of the information collected, enhancing the credibility of the writing, and making accurate conclusions (Jocius and Shealy 2017). This step entails fine-tuning the information into a report, which shows the flow of similar ideas. Selection of information such as sustainable agriculture, human development, inclusivity and growth of economies, and sustained production and hence food security, were carried out chronologically to elucidate their implication on practical small-scale farming.

Step Five: Expanding the Information Search

Expanding the information search is usually done when there is a need for more information in the study. This process is considered when the collected materials are not giving enough data. Thus, expanding information seeking is the process or activity to obtain information using the above-mentioned methods.

14.2.3 Phase Three: Communication Segment

The communication segment entails analysis of the collected information and synthesis of the outcome. Once the information has been analysed and synthesised, a report (final document) can be drawn. This phase constitutes two steps and is explained as follows.

Step Six: Analysis and Synthesising Information

Analysing information entails cautiously examining information to understand, interpret, and explain the outcome (Gablasova et al. 2017). The process of analysing information involves identifying similar assumptions, connections between arguments and gaps and being able to reason from the evidence given. Once the information has been analysed, a synthesis of the outcomes is then carried out. Synthesising information means summarising the main points derived from the analysis step. Thus, all the points and ideas are put together to give a sound conclusion.

Step Seven: Draw Up a Report

A report is a document that presents information in an organised manner. In this instance, the report was logically presented to provide the audience with constructive arguments as far as small-scale farming is concerned (Gablasova et al. 2017). Drawing up a report may be done in several procedures depending on the objectives of the study. The step involves making conclusions and drawing recommendations for the study, as presented in this document. The following section describes the role of small-scale farming in Africa; cases in various countries are reviewed.

14.3 Opportunities for Small-Scale Agriculture

Given a rapidly growing population, the demand for food is increasing across the globe. Agriculture plays a significant role in the economic progress in several continents such as Asia and Africa (FAO 2018). While developed continents such as Australia, South and North America, Europe, and some parts of North Asia highly depend on services, tourism, and manufacturing sectors, Africa and South Asia still rely highly on the agriculture sector (Rozaki 2020). Thus, the agriculture sector still creates new growth opportunities to support millions of people who are in extreme poverty, especially in Africa (43 million) (Jafino et al. 2020). The pressure on food supply is exacerbated by the ever-growing population as well as the outbreak of diseases such as Cholera, Ebola, and the recent COVID-19. The latter pandemic has crippled economies around the globe, leaving several countries such as South Africa to substantially capitalise on various agriculture opportunities to safeguard food security and employment creation.

A report by Ulucak et al. (2020) on opportunities and threats in the agriculture sector revealed that the agriculture sector is likely to improve developing countries since it depends on natural resources such as land, water, and sunlight. Graddy-Lovelace (2020) stated that in rural and urban farming, more people are starting to grow their food specifically for the market and smaller portions for their consumption. These farmers are taking advantage of the high demand for fresh, readily available, and healthier food products in local markets. Thus, opportunities for agriculture to achieve sustainable food supply across the globe are substantial and some are discussed in the following subsections.

14.3.1 Human Development (Employment Creation and Income Generation)

Agriculture is widely regarded as the most important economic sector in Africa for the achievement of long-term human development. It employs over two-thirds of the continent's working population, resulting in the creation of 570 million jobs in the industry (Huma 2020). On a country level, it is predicted that the agriculture sector contributes an average of 15–30% of total product and about 30% of the value of exports, making it one of the leading income generators in Africa (Zeufack et al. 2020). In terms of its contribution to GDP, agriculture is a source of inspiration for economic transition.

According to projections, the sector will provide a significant contribution to food security, job creation, and revenue production in Africa on average (Funge-Smith and Bennett 2019). This demonstrates that agriculture offers employment opportunities that can be taken advantage of in poverty-stricken countries throughout Africa. In addition to providing employment possibilities, the sector is expected to provide a solution to food shortages, which are expected to worsen as a result of the COVID-19 pandemic in 2020.

14.3.2 Food Production

Figure 14.2 shows changes in food production in Africa with a specific focus on crop and livestock production.

According to the Comprehensive Africa Agriculture Development Programme (CAADP), Agriculture has been instigated as a driver of food production and economic transformation in Africa (FAO 2018). As shown in Fig. 14.2, the sector contributed around \$78 billion (United States Dollars) in 1980 and the contribution increased to \$196 billion in 2010 in terms of food production. Livestock has contributed more as compared to crop production due to its nutritional status, hence boosting economic growth through exports (Martin 2019). West Africa recorded 33% of the total food production in 2010 followed by North Africa and East Africa (23%), Southern Africa (14%), and central Africa (7%) (Fig.14.2). The rapid increase in food production is attributed to technological and institutional innovations creating more opportunities for rural households to venture into this sector. Food production creates an avenue for income generation schemes and a viable means for sustainable employment creation (TRALAC 2019). As such, food production in Africa following rapid growth in demand for fresh food products in the view of the ongoing pandemic creates viable opportunities for rural dwellers.

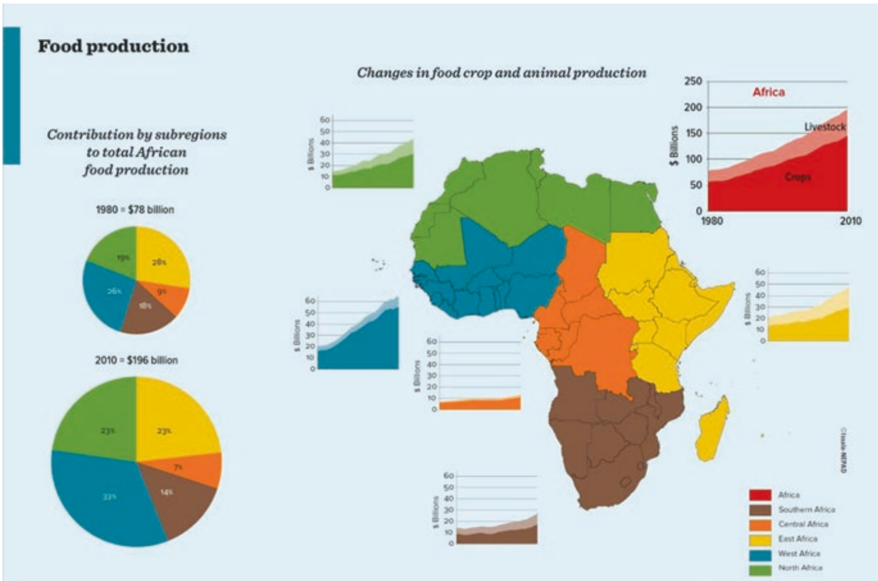

Fig. 14.2 Crop and livestock production changes in Africa. (Source: Trade Law Centre (2019))

14.3.3 Increasing Demand for Agricultural Products

Agriculture in Africa presents the limitless potential to tap into the ever-growing demand for agricultural products. Population growth, urbanisation, and changes in diets in areas such as the Middle East and Europe led to an increase in demand for African agricultural produce (FAO 2018). The increase in demand for African products presents an opportunity for the youth in Africa to add to the economic growth prospects. Furthermore, programmes such as the Comprehensive Africa Agriculture Development Plan (CAADP), Zero hunger challenge and Agenda 2063 consider agriculture as one of the viable sectors, hence creating opportunities for young people to contribute positively to Africa's development (Nhlapo 2020). Ultimately, the availability of natural resources and the agricultural investments and technology innovations create a viable opportunity for youths to participate in this sector as discussed in the following subsection.

14.3.4 Agriculture Investments and Technology Innovations

A report by FAO (2018) revealed that agricultural production tripled between 1960 and 2015, owing to investments and productivity-enhancing green revolution technologies and a significant expansion in the use of land, water, and other natural resources for agricultural purposes in Africa. In 2014, (the year of agriculture), African Union passed the Malabo declaration in which African countries committed to investing 10% of annual income every year into the agriculture sector (Matchaya et al. 2018; Hendriks et al. 2019). This shows that agriculture is still considered a viable sector because of a remarkable process of industrialisation and globalisation in this sector across Africa. The use of smart farming applications for record keeping and drones to fumigate the crops are some of the technologies slowly penetrating the sector (FAO 2018). However, obstinate and prevalent hunger and malnutrition remain a huge challenge in this continent and other parts of the world.

Considering the present rate of development, agriculture is envisioned to eradicate hunger by 2030, and sustainable development in many parts of Africa by 2050 (FAO 2018; Mason-D'Croz et al. 2019). Due to agriculture investments, the evolution of food systems has resorted to both changing dietary predilections and patterns, hence the inclusion of large-scale commercial farming in the supply chain. Integrating large-scale commercial farming in food production extends to product design, manufacturing, and delivery of fresh produce on a daily basis (Funge-Smith and Bennett 2019). However, the current increase in demand for food production creates opportunities for small-scale farmers to venture into the food production supply chain.

Market-oriented small-scale farmers have increased over the past decade, and this is attributed to the scale of change in food markets in developing economies. Agyepong et al. (2017) mentioned that a rural–urban supply chain growth rate of

600–800% was recorded in the last two decades in Africa and is expected to continue growing by 2030. This creates opportunities for small-scale farmers to take advantage of shifts in procurement, value chain coordination, and retailing. The inclusion of these farmers in the supply chain means more income generated, an increase in food supply, and creating employment through absorption of the local workforce in rural areas (FAO 2018). However, to successfully consider small-scale farmers into the supply chain, there are several challenges that need to be addressed and are discussed in the following subsection.

14.4 Challenges Faced by Small-Scale Farmers

Small-scale farming continues to play a crucial role in human development across Africa. However, several challenges are impeding sustainable growth such as climate variability, lack of appropriate agricultural infrastructure, high levels of soil degradation, shortages of farming skills, and harsh economic conditions (Lawson et al. 2019; Tessema and Simane 2019; Tahmasebi et al. 2020). Subsequently, these challenges have been exacerbated by the increase in dry spells due to climate change, unsustainable farming methods, water scarcity, degradation of ecosystem services, and biodiversity. Furthermore, the global COVID-19 pandemic led to a sharp rise in the cost of agriculture inputs, leading to increased pressure on small-scale farming productivity in Africa. Loeper et al. (2016) stated that small-scale farmers find it challenging to participate in the modern economy as the majority have limited access to credit since they do not have collateral security. In other parts of Africa, access to the market is one of the challenges making these farmers struggle to take part in the modern agricultural value chains (Rutsaert and Donovan 2020). Access to market challenge is also exacerbated by the quality of the yield which usually is characterised as of low quality and does not meet the required standards.

Technology adoption in this subsector has been emphasised in several regional and continental agrarian summits such as Agriculture Summit Africa (ASA), Africa Agric-Tech (AAT), and African Agri Investment Indaba (AAII) (Singh and Nath 2020). However, there are major barriers to adopting agriculture technology. The introduction of technology in small-scale farming is costly and sophisticated, leaving the majority of the farmers reluctant to invest in agri-tech farming (Singh and Nath 2020). This depicts that despite the availability of farming technology and its role in improving productivity (efficiency), there is a reluctance to adopt modern technology by small-scale farmers leading to poor yields (Agyepong et al. 2017). Furthermore, a lack of knowledge on input quality is also leading to the pervasiveness of poor farming methods resulting in poor yields, which are of low quality to what is anticipated in the market (Franke 2020). As such, being over-reliant on poor methods of farming is leading to substandard yields, making it difficult for these farmers to compete in local, national, and international markets (Rutsaert and Donovan 2020). A study by Franke (2020) revealed that small scale-farmers' competitiveness is hindered by the quality of their products which creates a stringent barrier to participating in fresh food supplies.

Poor and inadequate infrastructure in rural areas such as access to roads, water, and lack of rural electrification are some of the challenges faced by small-scale farmers in Africa (Mburu and Massimo 2018). Poor infrastructure in rural areas is mainly caused by poor investments as a result of corruption, political influence, absence of incentives, poor accountability, and less political concern given (Khumalo and Mji 2014; Naher et al. 2018). Thus, poor road networks are causing challenges like access to the markets and transportation of raw materials from the markets to the farms. Most of the farmers are located in peripheral rural areas where there are no tarred roads and less investment in water reservoirs. Against these challenges, it is pragmatic to suggest solutions that can be used to improve small-scale farming development in rural areas. Likewise, the following solutions have been suggested and it is envisaged that they enhance small-scale farming and its contribution to food security in Southern Africa.

14.5 Agriculture Development Solutions

Solutions to the challenges faced by small-scale farmers may result in improving the sector, hence a positive contribution towards food security and sustainable income generation schemes (FAO 2017; Pawlak and Kołodziejczak 2020). Development in areas such as infrastructure investments, climate, information technology, human capital, and research and innovation may improve the face of small-scale farming (Pawlak and Kołodziejczak 2020).

14.5.1 Climate Change Solutions

First, climate variability may cause stringent challenges on small-scale commercial farming development (Lobogurrero and Campbell 2019). However, there is a need to commit to a sustainable future by focusing on training small-scale farmers in terms of effective irrigation management, hence conserving water use in this type of farming. This can be supplemented by advocating for the use of climate-resistant hybrid seeds and lucrative organic practices. Thus, water conservation and maximising energy efficiency through advocating for the use of renewable energy in small-scale farming may also lessen the climate change variability in this sector (Harvey 2018). The use of renewable energy involves on-farm renewable energy production, namely, introducing wind turbines and solar panels for energy generation, reducing the dependence on fossils fuel inputs, and maximising the use of petroleum-based fertilisers. The use of drought-tolerant seeds, water conservation plans, and redesigning the agroecosystems, such as incorporating trees and native planting perennials, are some of the climate-smart agriculture practices (Altieri and

Farrell 2019). In this regard, reducing the damage of climate change and building climate-resilient agriculture will require major policy changes, which incline towards redesigning them as diverse agroecosystems.

14.5.2 Infrastructure Investments

Lack of appropriate agriculture infrastructures such as roads, storage facilities, resources and farming equipment require immediate intervention by the government and private sector. A focused investment by the government should aim at enhancing small-scale farmers' awareness of social trust and incessantly encouraging the governance capacity of the rural-based infrastructure development (Savary et al. 2020). This can be achieved through improving the role of rural community self-governance and prioritising socioeconomic forces in agricultural infrastructure construction. While that is the case, there is also a need to actively involve the private sector to participate in agricultural infrastructure construction so that small-scale farmers can obtain more practical benefits. In so doing, the government should also enforce infrastructure investments policies that speak to transparency, non-discrimination, and policy rationality, which can limit corruption in infrastructure development service delivery. Accordingly, Sivakumar (2018) suggested that sectorial investment policies in agriculture-based communities should be aligned with agrarian investment strategies, hence clear guidelines and transparent procedures. Investments in irrigation and transport infrastructure should be promulgated focusing on improving small-scale farming mainly in rural areas.

14.5.3 Information and Communication Technology Investments

Investing in information and communication technologies is pivotal to enhancing access to information on agriculture production in this type of farming. Access to information technology may contribute to a well-functioning system in terms of accessing vital materials for sustainable farming (Chen et al. 2020). The majority of the farmers face limited access to information which in turn limits their development, hence linkages between small-scale farmers and other stakeholders through access to information may foster knowledge transfer. As such, the private sector such as telecommunication subsidiaries should be encouraged to tap into small-scale farming communication technologies development (Bacco et al. 2019). Communication technology may help small-scale farmers in remote areas to have access to information which could make operations more financially viable. Also, access to timeous information is advantageous in involving small-scale farmers in the agriculture supply and value chain. (Luthra et al. 2018) The introduction of the agro-based industry would require an effective communication system which would increase the exchange of timeous information. Resultantly, investment in information and communication technology would also improve nationwide connectivity, which will benefit many industries, including the agricultural supply chain.

14.5.4 Research and Innovation

Investing in human capital through dynamic agriculture innovation systems is vital for improving small-scale farming. Human capital development-centred policies should support high-quality education in farm owners and workers through the promotion of national research in this sector (Agyepong et al. 2017). Thus, public research and development focusing on human capital have the potential to facilitate technology knowledge transfer in small-scale scale farming. Resisting the adoption of modern technology may be caused by a lack of knowledge on the use of farming technologies. Hence, linkages between public research, the use of technology training, and investing in human capital may promote the rapid adoption of new farming techniques and the use of technology (Chen et al. 2020). Accordingly, small-scale farmers could be equipped with a technology-oriented skills base, making it easy for the adoption of agrarian technology in this sector. Furthermore, research and innovation with a specific focus on human capital may also promote the introduction and adoption of clean and energy-efficient technologies (Nangavi 2020). In this regard, policies that favour research and innovation for small-scale farming human capital development should be instigated.

14.5.5 Investing in Agriculture Training

Agriculture training is another comprehensive solution to the challenges faced in small-scale farming (Bacco et al. 2019). Training in areas such as farm management, financial literacy, and the use of technology in farming may help small-scale farmers to incorporate the latest scientific advances and technology tools. Subsequently, agriculture education and training cover a broad range of agrarian activities, which would build capacity for investments in this sector. For instance, Boakye (2018) suggested that investment in technology would require training on how to use such technologies, hence training (knowledge and skills acquisition) is positively related to efficacious development. In this regard, budgetary actions to support investments in training small-scale farmers on farmland conservation, renewable energy, water stewardship, healthy soils, and other sustainable practices may assist in enhancing productivity in the type of farming.

14.5.6 Practical and Policy Implications

Multi-stakeholder and multisectoral support of small-scale farming in Southern Africa is paramount given that both rural and urban dwellers rely on small-scale farmers for food production and supply (Funge-Smith and Bennett 2019). There is huge potential for sustained small-scale farming and improvement in food nutrition security in the region. Research on how many small-scale farmers indeed are contributing to food security is key given that it has been observed that few operating on a large scale are contributing. Results will be used to identify those willing to participate and the obstacles they are facing to devise targeted solutions with them. Venturing into innovative and technology-oriented research with the farmers is also critical to identify and prioritise crops and livestock to focus on, for sustainable small-scale farming and significant contribution to food security in the region. It is pertinent to consider non-climate change prone crops and livestock (Franke 2020). Furthermore, appropriate farming approaches that are environmentally friendly and have extremely minimised damage to the ecosystem must be adopted. This is because there is a close linkage between food security and sustainable agriculture and hence sustainable small-scale farming. Thus, sensitivity to agroecology and biodiversity is vital. These tally with the need for organic farming that is preferred for health reasons.

Policies that create a conducive environment for human capacity development, co-knowledge generation, co-learning and transfer of knowledge, technology, and skills are vital for improving small-scale farming in Southern Africa. For example, Graddy-Lovelace (2020) stated that education of farmers and enabling environment for farming is crucial for reducing soil degradation, enhancing enthusiasm, especially of youth and farming skills, and use of technology. Some farming conditions are not conducive due to poor infrastructure, reduced access to credits, markets, and information. It is, therefore, crucial for both research and policies to be conducted and devised or reviewed, respectively, for the betterment of small-scale farming in Southern Africa (Altieri and Farrell 2019). This assists the farmers to be rich with the necessary information and be of value in the agricultural value chains through generous information asymmetry.

Focus by the government and private sector on improving infrastructure is critical especially because most small-scale farmers are at the periphery of rural areas where there are no tarred roads, electricity, and there is less investment in water reservoirs (Bacco et al. 2019). Linked to this, enforcement of infrastructure investments policies that speak to transparency, non-discrimination, and policy rationality that promote inclusivity in access and infrastructure development service delivery is paramount. Training on ICT and subsidised communication technology may help small-scale farmers in remote areas to have access to information timeously thereby making operations more financially viable (Chen et al. 2020). In Southern Africa, the availability of natural resources presents opportunities for sustainable development that needs to be sustainably tapped into. Further, the encouragement of an active citizenry is fundamental to the growth and development of rural communities, leading to sustainable agriculture in the region.

14.5.7 Science Communication

With the advent and advancement of technology and the need for information sharing, it is critical to foster science communication. The small-scale farmers and all their key stakeholders would need to take advantage of the wide dissemination of information through credible media platforms such as Twitter, radio talk shows, TV shows, online or hard copy popular articles, Facebook, and, local and world newspapers (Trade Law Centre 2019). The use of native languages is pertinent in addition to other languages such as English, Afrikaans, French, and Spanish that are mostly used on communication platforms and in Southern Africa. Translating to locally used languages in the region would be just as well for reaching out to all the small-scale farmers. Native languages encourage the active participation of small-scale farmers in the debates for improving food security in the region and enhancing their contribution on the ground (Altieri and Farrell 2019). This helps to transmit information that helps stakeholders for collaborative action towards sustainable agriculture in the region. Such modes of information dissemination promote learning and sharing and a wider distribution of information to the wider public. This is critical for applied research and development that makes an impact on society and changes lives.

14.6 Conclusion

Small-scale farmers have a role to play in the development of rural communities in terms of employment creation, income generation, and food security. These roles have been emphasised in national and international programs such as NDP 2020, Zero Hunger Challenge, Agenda 2063, and SDGs (1 & 2). In Africa, it has been revealed that indeed the development of this sector may offer a progressive outlook in terms of human development and further contribute to the national GDP. This shows that undeniably national economic development relies on agricultural growth, hence the need to support farmers in the agriculture sector with a specific focus on small-scale farmers who are playing a crucial role in feeding rural communities and contributing to significant growth and development of these communities and beyond. Fundamentally, a review of published literature (second-hand data) from published books, journals, and online portals in a three-phase strategy revealed that there are several opportunities for small-scale farming agriculture to contribute to food security and income generation further positively in the face of a rapidly growing population.

Opportunities such as, but not limited to, employment creation, food security, and income generation are likely to be achieved given the availability of natural resources in the continent, the ongoing agriculture investments, and the availability of technology innovations. However, it has been revealed that chronic challenges are hampering the probable development of the small-scale farming sector. Challenges such as climate variability, lack of appropriate agricultural infrastructure, high levels of soil degradation, shortages of farming skills, and harsh economic conditions have been noted. Furthermore, these challenges have been exacerbated by the increase in dry spells due to climate change, unsustainable farming methods, water scarcity, degradation of ecosystem services and biodiversity. Therefore, agriculture development solutions such as climate change solutions, infrastructure investments, information and communication technology investments, research and innovation, and investing in agriculture training may lessen, if not eradicate, the challenges faced. Considered as such, multi-stakeholder and multisectoral support in small-scale farming is philosophical. Conclusively, policies that create a conducive environment for human capacity development, co-knowledge generation, co-learning and transfer of knowledge, technology, and skills are vital for improving small-scale farming.

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Chapter 15
Improving Food Security in Africa Through Sustainable Utilization of Selected *Climate Smart Emerging Crops*: A Case of Botswana and Namibia

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15.1 Introduction

Food security remains a serious threat in Africa with 256 million people being undernourished as of 2018 (FAO 2019). Of these, the sub-Saharan African region has the highest prevalence of undernourishment, at almost 20%, which is about four times that of any other region (FAO 2019). This has been compounded by many factors, including climate change, water scarcity, political unrest, insufficient land resources and very recently the global pandemic COVID-19. The emergence of COVID-19 has disrupted food trade activities resulting in shortage of food supply and increased transportation cost and consequently increased food prices which further threaten food security of Africans (Fernandes 2020; Gilbert et al. 2020; Ayanlade and Radeny 2020; FAO 2020a). The sudden lockdowns in some cases coincided with harvesting season, forcing farmers to abandon their produce. This not only led to loss of farm produce but also to loss of profit, which negatively affected the food security and economy, especially of the poorest (Ayanlade and Radeny 2020).

In order to find sustainable solutions to food security challenges, it is important to investigate the indigenous and emerging plant resources herein referred to as *climate smart emerging crops* as they have demonstrated the ability to cope with climate change and combat the effects of climate change which are especially affecting marginal populations in Botswana and Namibia. These have also

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demonstrated potential to contribute to food and nutrition security and income generation. Some of these *climate smart indigenous plants*, such as morama bean (*Tylosema esculentum* (Burch.) A.Schreib.), mungongo (*Schinziophyton rautanenii* (Schinz) Radcl.-Sm.), mosukujane (*Lippia javanica* (Burm.f.) Spreng), moringa *(Moringa olifera* Lam), Kgengwe (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) and mahupu (*Kalaharituber pfeilii* Trappe), have extensively been studied under several projects in Botswana, South Africa and Namibia (Mogotsi et al. 2019; Manyeula et al. 2018; Khonga et al. 2005; Mogotsi and Ulian 2013). These plants are found across East and Southern Africa where they are staples for indigenous communities (Ulian et al. 2014; Mogotsi et al. 2019). These also have been shown to possess high nutritional value as well medicinal properties and thus have a great potential in improvement of human health (Mongalo et al. 2015; Lakshmipriya et al. 2016). In many African countries, the broad base of indigenous food plants has been a reliable food source for many communities and provided a major nutritional supply especially during the dry spells or during famine as a buffer against food shortages and to sustain livelihoods in drylands and marginalized communities (Legwaila et al. 2011). Domesticating and commercializing these plants could make them become more accessible to groups highly vulnerable to climate change effects, such as women, youth and people living with disability who are also facing poverty (Mogotsi and Mogopodi 2021; Ulian et al. 2014, 2019; Manyeula et al. 2019), and enhance evidence on the role of indigenous crops in agricultural resilience.

15.1.1 Nutritional and Medicinal Properties of Selected **Climate Smart Emerging Crops**

The *climate smart indigenous plants* selected herein, morama bean (*Tylosema esculentum* (Burch.) A.Schreib.), mungongo (*Schinziophyton rautanenii* (Schinz) Radcl.-Sm.), mosukujane (*Lippia javanica* (Burm.f.) Spreng), moringa *(Moringa olifera* Lam), Kgengwe (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) and mahupu (*Kalaharituber pfeilii* Trappe), have the potential to be a source of food enricher in a broad array of dietary nutrients including proteins, fibre, vitamins (Lekalake et al. 2014; Nyathi et al. 2018; Matenge et al. 2011; Erhirhie and Ekene 2013) and macro and micro-elements such as Zn, Vitamin C and Vitamin D (Mogotsi and Mogopodi 2021; Tlili et al. 2011; Lakshmipriya et al. 2016), especially needed during COVID-19 possibly to contribute to the normal functions. In addition, they have a great potential for combating malnutrition – a burden that Africa continues to bear (Jackson et al. 2010). Research has also shown these plants are rich in bioactive phytochemicals such as flavonoids, alkaloids as carotenoids, phytosterols, and tannins (Basu et al. 2007; Maroyi 2017; Mariod and Abdelwahab 2012; Muok 2019) and thus have the potential to provide protection against diseases including non-communicable diseases such as cardiovascular diseases, diabetes and cancer (Gbadamosi et al. 2017; El Enshasy et al. 2013; Kwaambwa et al. 2012). The bioactive compounds found in these food plants have also been linked to health benefits such as antidiabetic properties and are considered antiplasmodial, antibacterial, antifungal, anti-inflammatory and antidiarrheic (Mariod and Abdelwahab 2012). *M. oleifera* for example has enormous medicinal potential, which has long been recognized (Farooq et al. 2012). *M. oleifera* extracts have shown a myriad of nutraceutical or pharmacological properties including anti-inflammatory, antioxidant, anti-cancer, cardiac and circulatory stimulant, hepatoprotective, neuroprotective, analgesic activity, hypoglycemic, antimicrobial activity, anticholesterol activity, anti-diabetes activity, antibacterial activity and blood lipid-reducing functions (Dixit et al. 2016; Seifu and Teketay 2020; Kwaambwa et al. 2012). Mahupu (*Kalaharituber pfeilii* Trappe) contains essential fatty acids which are known to reduce associated cardiovascular morbidity and mortality, prevent cancer prevention, and help reduce hypertension and diabetes mellitus. Mahupu (*Kalaharituber pfeilii* Trappe) constitutes high concentrations of monounsaturated fatty acids, with oleic acid being significantly high which is known to reduce the risk of coronary heart disease (Sawaya et al. 1985; Ferdman et al. 2005; El Enshasy et al. 2013). Morula has been found to have many micronutrients. Of these micronutrients, vitamin C is found in high concentrations, as high as 180 mg vitamin C per 100, which is much higher than in most citrus fruits (Van Wyk and Gericke 2000; Hilman et al. 2008).

However, there is a concern over the diminishing value of indigenous food plants largely due to modernization whereby they seem to be regarded as primitive and inferior (Mabhaudhi et al. 2019). It is thus critical to continuously build and publicize food nutritional composition data and highlight medicinal properties of indigenous food plants in order to promote their incorporation into daily diets. The medicinal properties of the morama bean (*Tylosema esculentum* (Burch.) A.Schreib.), mungongo (Schinz) Radcl.-Sm, mosukujane (*Lippia javanica* (Burm.f.) Spreng), moringa (*Moringa olifera* and *Moringa ovalifolia*), kgwengwe (*Citrullus lanatus*) (Thunb.) and mahupu (*Kalaharituber pfeilii* Trappe) are shown in Table 15.1. Table 15.2 further highlights functions of a few selected phytochemicals and vitamins attributed to medicinal properties in some of these plants (this is not exhaustive).

15.1.2 Economic Strategy

The selected *climate smart indigenous plants* in Southern Africa have the potential to fuel economic growth for the governments and contribute to Gross Domestic Product growth significantly. Morama (*Tylosema esculentum*), for example, has been shown to have economic potential and its successful experimental cultivation has been reported (Chimwamurombe et al. 2010; Mogotsi and Ulian 2013). However, the exploitation of these species for economic purposes is still very low (Kasimba 2018; Muok 2019), thus prioritizing them for commercial farming is essential in order to ensure their continued contribution to food and income security (Ulian et al. 2014; Jusu and Cuni-Sanchez 2017) and reduce poverty especially in

Table 15.1 Medicinal properties of selected *climate smart indigenous plants*

Plant	Medicinal properties	Reference
Moringa oleifera Parts used: seed, leaves, bark and/or roots	Treatment of diabetes, rheumatism, diabetes, hypertension, arthritis, weakened immune system, ulcers, ankle and knee ailments, flu, stomach diseases, reduces fatigue, improves appetite and indigestion, relieves menstrual pain	Seifu and Teketay (2020) Kwaambwa et al. (2012)
Tylosema esculentum (Burch.) Morama	Treats diarrhoea, stomach cramps, enhances milk production in lactating mothers and increases appetite, improves blood circulation, oil used as a cleanser for girls after first menstruation and oils are also used as lotion to prevent skin itchiness	Chingwaru et al. (2007)
Mosukujane (*Lippia javanica* (Burm.f.) Spreng) (leaves, stem, roots, twigs)	Traditionally used for treatment of colds, cough, fever or malaria, wounds, repelling mosquitos, diarrhoea, chest pains, bronchitis and asthma	Maroyi (2017)
Morula (stem-bark, leaves)	Antidiabetic properties, antiplasmodial and antimalarial properties, antibacterial, antifungal, anti-inflammatory, antidiarrheic activity, analgesic, molluscacidal, antispasmodic properties	Mariod and Abdelwahab (2012)
Kgengwe (*Citrullus lanatus*) (Thunb.) (Fruit, seeds, leaves)	Seeds used in treatment of urinary tract infections, alcohol poisoning, hypertension, diabetes and gonorrhoea	Erhirhie and Ekene (2013)
Mahupu	Applications as anticancer, antimicrobial, antioxidant, anti-inflammatory, hepatoprotective, cholesterol and sugar-lowering agent	El Enshasy et al. (2013)

Table 15.2 Functions of selected phytochemicals and vitamins attributed to medicinal properties of some *climate smart indigenous plants*

Phytochemical	Function
Tannins	Direct and indirect antioxidants, anti-cancer activities, neurodegenerative diseases
Phenolic acids	Protection against oxidative stress-related diseases, reduction, reactions which aid in the prevention of degenerative diseases such as diabetes
Flavonoids	Neurodegenerative diseases, delayed onset of some age-related diseases, positive effects on cancer-related diseases, positive effects, potent cancer-related diseases
Glucosinolates	Mitigate effects associated with oxidative stress, possess anti-cancer activities. Protective against neurodegenerative diseases
Vitamins	
Vitamin A	Enhancing the skin barrier function
Vitamin B	Involved in DNA synthesis and cell division
Vitamin C	Synergy with other vitamins and minerals to support the protective activities of the immune cells

marginalized communities. It is within the Botswana government's strategy to increase the effectiveness with which natural resources – indigenous plants included – are used and managed in order to optimize economic benefits by carrying out the following: developing new and better uses of natural resources, which are sustainable; optimizing existing uses of all natural resources including indigenous plants, as well as develop multiple rather than single-purpose, natural resource uses (National Biodiversity Strategy and Action Plan 2016). The optimization of *climate smart indigenous plants* will allow for diversification of commercial uses of these plants, increase dietary options for the country as well as diversify the rural economy to generate new jobs. The government also through the Ministry of Agricultural Development and Food Security is empowering various institutions related to the plant genetic resources material through in situ and ex situ conservation so as to rejuvenate, multiply, evaluate and document the plant genetic resources material collected (National Biodiversity Strategy and Action Plan 2016).

On the other hand, Namibia has recognized the need to develop strategies for coordinating indigenous natural products utilization and commercialization by different stakeholders. Thus, the Indigenous Natural Product policy network in Namibia is multi-dimensional and constitutes a number of special governance bodies for coordinating different indigenous natural products activities (Du Plessis 2007; Ndeinoma et al. 2018). These include Indigenous Plant Task Team (IPTT), which is the central node for INP governance including resource mobilization and information sharing, and functional relations, which serve specific roles in the INP value chain and facilitate policy development, particularly for heavily regulated species (Ndeinoma et al. 2018). IPTT coordinates sustainable commercialization of INPs in Namibia, including development of a variety of pilot projects on propagation and domestication, chemical and nutrient analysis, development of technology and processing methods and marketing initiatives (Ndeinoma et al. 2018).

Despite these efforts, markets in Botswana, Namibia and other developing countries have shown preference for non-native food plants over indigenous food plants (Kasimba et al. 2019; Bvenura and Afolayan 2015). Exotic food plants are widely promoted, and their uses and management techniques are well known while there is paucity of data information on indigenous food plants and on product development from these plants. This is due to a lack of focus on research and development of these plants despite their large market potential (Bille et al. 2013). The sale of indigenous food plants has been mostly limited. In Botswana for example only a few population; in particular women and youth, have been engaged in the sale of indigenous food plant produce, in both formal and informal markets in rural and urban areas (Legwaila et al. 2011; Kgosikoma et al. 2020). Moreover these indigenous food plant produce are mostly sold from homes, near shopping centres and from door to door and roadside markets. Most indigenous food plant products, for example, Morula products, are mostly sold in informal market with lower sales of these products in the (Ndeinoma 2018; Bille et al. 2013; Kgosikoma et al. 2020; Taylor et al. 1996). The markets are seasonal and very limited. The factors that contribute to slow formalization of markets include seasonal and limited markets, lack of infrastructure, limited supply of products, inconsistent quality of products and paucity of data regarding sustainability, transformation and value addition of products from these indigenous food plants (Bille et al. 2013). It is thus critical to develop economic strategies that enhance uptake of indigenous plants by exploring the potential of domestication and cultivation, development of value-added products, commercialization, intellectual property management for indigenous food, as well as strengthening science–policy interface in research and development domestication.

15.2 Exploring Potential of Domestication and Cultivation

The potential of domestication and cultivation of indigenous food plants could be explored in order to improve food security and cash income for people living in marginalized communities. This could also be a strategy to mitigate climate change and counter desertification. The domestication of indigenous plants could offer advantages such as high yields, minimum use of water, fertilizers and pesticides (Shelef et al. 2017) due to better adaption to their homeland environment. By domesticating indigenous plants genetic diversity is developed and promoted and these indigenous plants could serve as a genetic bank (Palmgren et al. 2015; Leakey et al. 2005a, b; Leakey 1999) mitigation of soil erosion and conservation of plant–microbe–soil interactions.

In domesticating indigenous food plants, it is critical to identify and select species with economic potential, medicinal and nutritional value (Ulian et al. 2014; Leakey 1999; Taylor et al. 1996). Other factors that are often considered include the ethnobotanical importance (Nkosi et al. 2020), the length of the fruiting period, the ease of propagation and resistance of the plants to harsh climatic conditions (Agea et al. 2007; Bvenura and Sivakumar 2017).

Research and development initiatives have been undertaken to domesticate and cultivate some priority *climate smart emerging crops* (Mogotsi et al. 2007); examples of propagation, experiments and marketing of seeds collected by these communities are shown in Figs. 15.1, 15.2 and 15.3. Through external funding, various projects on *climate smart emerging crops* have been conducted in Botswana, which led to the establishment of community gardens including school gardens. The establishment of gardens in schools is especially important in that it could create a sense of pride on cultural food systems at an early age and can be a catalyst in building future interest in domestication of indigenous plants. In addition to garden establishment, experiments and training in cultivation and management have been done to enable communities to carry out activities independently. Where seeds were difficult to propagate, techniques which increased germination rates such as 'liquid

Fig. 15.1 Morama bean (*Tylosema esculentum*) cultivation experimental plots *and Morama seed sold in the informal market.* (*Source*: Ulian et al. 2014)

Fig. 15.2 Cultivated tree of *Schinziophyton rautenenii* (mongongo (/Qom)), seedlings and tree trunk storing water

Fig. 15.3 Morama tuber response to compost (biochar), soil types and watering variations. (*Source*: Mogotsi and Mogopodi 2021)

smoke' were developed in order to overcome seed dormancy, and these techniques were passed on to African tree centres and training of local people was done on how to collect and germinate seed (Mogotsi and Ulian 2013). The potential for domestication of Morula has been demonstrated in Botswana, Namibia and South Africa (Mogotsi et al. 2007; Leakey et al. 2005a, b; Mojeremane and Tshwenyane 2004). It has also been shown that there is opportunity to select cultivars for kernel production for Morula to meet the needs of markets for nutritious kernels and various oil industries (Leakey et al. 2005a, b). The cultivar selection could increase uniformity in the product, increase productivity and provide an incentive for farmers to cultivate Morula trees in their farming systems (Leakey 2001).

There are of course several factors that limit full success of domestication: the lack of policy on the domestication, cultivation and conservation of indigenous plant species, limited knowledge of plant reproductive biology, plant diseases and pests' complex, climate variability and its impact on biodiversity (Kumssa et al. 2017). In waterlogged areas, plants such as Moringa trees can rot and die. Other constraints include poor farm infrastructure, lack of business or low demand for these plant products, lack of production and marketing skills by producers, unknown dosage of plants' edible parts used as medicine, and uncertainty about the nutritional and medicinal values of these plants (Kumssa et al. 2017). Despite these challenges, communities have shown interest in prioritization of *climate smart emerging plants* for research, development, domestication and commercialization (Ulian et al. 2014). Table 15.3 lists plant species prioritized by communities in Botswana for domestication, cultivation and commercialization.

Table 15.3 Selected *climate smart emerging crops*, uses and products as described by local communities in Botswana

Scientific name	Setswana name	Uses	Products
Tylosema esculentum	Morama	Food, medicine, environmental services	Oil, milk, yogurt, butter, snacks, protein-rich flours, provides soil cover and soil nutrients recycle
Citrullus lunatus	Kgengwe	Food, fibre, medicine, environmental services	Water, seed oil, pickles, juice, wine, alcohol, porridge
Kalaharituber pfeilli	Mahupu	Food, medicine, environmental services	Oil, flavonoids, reduces cholesterol boost immunity, high in antioxidants, nutrient recycle
Sclerocarrya birrea	Morula	Food, medicine, environmental services	Oil, juice, wine, alcohol, vitamins, minerals, household utensils, agricultural tools, etc.
Schinziophyton rautenenii	Mongongo (/Qom)	Food, fibre (matches), medicinal, building/roofing (bark), seedling succulent	Oil, milk, snack, soup, juice, wine, alcohol, dugout canoe
Moringa olefera	Moringa	Treatment of diabetes, rheumatism, diabetes, hypertension, arthritis, weakened immune system, ulcers, ankle and knee ailments, flu, stomach diseases, reduces fatigue, improves appetite and indigestion, relieves menstrual pain, water treatment	Oil, juice, capsules, spice, beverage, antioxidant, anti-inflammatory, cosmetics, soap, press cake powder, confectionary

Source: Ulian et al. (2014); Mogotsi and Mogopodi (2021)

In sandy soils, morama tubers were elongated while improving soil using different biochar produced rounded tubers. Morama also responded to different levels of irrigation and soil types.

15.2.1 Intellectual Property Management for Knowledge and Protocols

Critical to the success of utilization and commercialization of indigenous plants is the participation of indigenous people in developing appropriate intellectual property frameworks for access and use of their knowledge and knowledge practices (Bagley 2018). This is key considering the historical exploitation of indigenous knowledge, especially by multinational companies, which directly utilized indigenous knowledge without benefiting the indigenous people. In 2001, for example, the

Council for Scientific and Industrial Research in South Africa filed for several international patents on the Hoodia plant, which the San, an indigenous group based mainly in Botswana, Namibia and South Africa, had used as a natural appetite suppressant from as far back as the 1930s. CSIR did not involve the San as key stakeholders; neither did they acknowledge them as the originators of the knowledge that led to the patents, thus denying them the economic benefits derived from commercialization (Wynberg et al. 2009). The University of California and Lucky Biotech, a Japanese corporation, was granted a patent for the sweetening proteins naturally derived from African plants, katempfe and serendipity berries, without sharing benefits with local communities despite these having been historically used by Africans for their sweetening properties (Roht-Arriaza 1996). Advancing indigenous peoples' participation in intellectual property is key considering that indigenous communities hold valuable knowledge in areas such as conservation, agriculture and healthcare and that they have been using for centuries to preserve their livelihood and should not only be the responsibility of indigenous peoples but should also be the responsibility of researchers, policy makers and national government.

In this context, World Intellectual Property Organization has developed international legal instruments that give traditional knowledge (TK)/Indigenous Knowledge Systems (IKS) and genetic resources protection (https://www.wipo.int/pressroom/en/briefs/tk_ip.html). The Botswana Parliament itself passed the Industrial Property Act, 2010, to incorporate the protection of TK. The benefits for protecting TK and IKS are varied and include wider application of traditional knowledge throughout the world, preservation of traditional lifestyle, protection or preservation of the environment and more recognition of the value of traditional knowledge, and more resources for the custodians and raising standards of living particularly in the developing world (WIPO 2011).

In view of the importance of TK, under UPP and Morama Bean Project, researchers in Botswana worked closely with communities and prioritized indigenous peoples' participation in research activities (Ulian et al. 2014). Participatory needs assessment to establish the importance, sustainable utilization, prioritization of research and development, as well designing of research activities were carried out in different local communities and during different consultative meetings across the country. This participative approach developed local community ownership and allowed for successful collaboration and successful implementation of research findings while at the same time ensuring indigenous peoples have access to research findings derived from their knowledge systems. This approach could achieve societal breakthrough as it recognizes the key role indigenous people could play in the fight against food insecurity. Under these projects, research findings were disseminated in local and international platforms: media, journals and further the researchers and collaborators participated at national trade fairs and shows. As a way of knowledge sharing, books and guideline materials denoting nutritional composition and use of indigenous plants were written and some material was written in the vernacular by indigenous San people, an indication of ownership of their knowledge (Ulian et al. 2014). The practice of sharing research findings with indigenous people particularly in their language cultivates trust between researchers and the community (KuHnlein et al. 2004).

The researchers also incorporated local community practices into research projects and gave local communities a platform to exchange knowledge such as on cracking of oil seeds; this is a recognition of communities' members being custodians of traditional knowledge. In addition, the local communities were trained in more improved food processing such as the introduction of cold press oil extraction machines for communities to produce oils. Because of these efforts, there has been a rise in confidence in entrepreneurial development by women and youth using *climate smart emerging crop* as raw materials. Training communities is key as the success and sustainability of food-based interventions at the community level involves capacity building and behaviour change to improve food availability and use. These activities can offer a pathway out of poverty. All these activities could be a good model for promoting utilization of *climate smart emerging crops*, and consequently improve food security. Figure 15.4 shows technologies on *climate smart emerging crops* and *products'* traditional and modern methods of extraction, and this is a demonstration of the successful exchange of knowledge between communities and researchers.

Fig. 15.4 Technologies on *climate smart emerging crops* and *products'* traditional and modern methods of extraction. (*Sources*: Ulian et al. 2014; Mogotsi et al. 2019)

It is necessary to have contextually driven protocols and guidelines for indigenous knowledge suitable for these holders, including those that are not literate, on appropriate steps to take in the event that the third party is interested in obtaining access to their indigenous knowledge and/or indigenous biological resources (Dutfield 2015; Anderson 2010). This could help indigenous people and communities to make informed decisions about the extent of knowledge use permissible and give an understanding of financial benefits that will be returned. To enable implementation of such protocols, Botswana has been a party to the Nagoya Protocol since its entry into force in October 2014 (https://www.cbd.int/abs/nagoya-protocol/signatories/).

The Nagoya Protocol is a supplementary agreement to the United Nations Convention on Biological Diversity (CBD) that focuses on access to genetic resources and the fair and equitable sharing of the benefits arising from their utilization (ABS). Through these legal frameworks, the governments of Botswana and Namibia strive to facilitate legal protection and fair terms in negotiations and help ensure that local communities benefit economically from their traditional knowledge and the rich biodiversity around them. Botswana and Namibia are also a party to International Treaty on Plant Genetic Resources (FAO 2020b). The International Treaty on Plant Genetic Resources for Food and Agriculture is a landmark international agreement for ensuring food security and sustainable agriculture, especially in developing countries. The treaty through its objectives seeks to ensure the conservation of plant genetic resources for food and agriculture and aims at promoting the sustainable use of plant genetic resources for food, agriculture and its components, and it strives to ensure fair and equitable sharing of plant genetic resources for food and agriculture (Tabaro 2009). The ITPGR requires that certain genetic materials held by the centres be designated to remain in the public domain and free access by the world community.

15.2.2 Forms of Protection That Can Be Utilized

15.2.2.1 Utilization of Labelling and Geographical Indications

One of the ways in which indigenous people can protect products, especially when the value of the product is tied to its derivation within a particular context or by a particular group within a market, is through the utilization trademarks, certification marks and marks of origination (Anderson 2010). These different types of intellectual property can be used for marketing purposes and could play a key role in the growth of developing country markets. Geographical indications (GIs) are a form of protection that utilize the name of a region or area where a product originates (WTO Analytical Index 2020). Functioning in similar ways to trademarks and other forms of labelling, GIs help a consumer to identify products and ensure that they have a certain quality and reputation. These can be utilized to prevent the misleading use of any means in the designation or presentation of a good that indicates or suggests that the good in question originated in a geographical area other than the true place of origin. Article 22 of the TRIPS agreement states that governments must provide legal opportunities in their own laws for the protection of GIs. Botswana has acceded to the TRIPS Agreement, and therefore has incorporated its GI provisions in domestic legislation. Practically, however, the absence of domestic law makes application of the agreement very difficult.

GIs could be beneficial, especially when traditional communities have products that are attractive to domestic and international markets products with a niche market, both domestically and internationally. These must first be protected locally, and Article 22 provides the means for this (WTO Analytical Index 2020). Enforcement of GIs requires lot of funding which is a challenge to traditional communities. In order to products derived from natural resources indigenous to a specific territory through GIs, their name should not be generic or semi-generic, either internationally of locally, and thus it is important for these communities to guide against the name becoming generic. Holders of TK would thus only benefit if they act proactively in the protection of bioresources (WTO Analytical Index 2020).

Another form of protection of TK is in patent protection, which however requires the three criteria for patentability, namely novelty, non-obviousness and usefulness, to be satisfied. TK would fulfil this utility requirement as it has been utilized for generations within the community but it is often difficult to fulfil the requirements of novelty and non-obviousness, because normally TK would have been passed from one generation to another and may furthermore be known to other members of the community and in addition it is difficult to pin point the originator of a specific TK. This makes patent protection difficult to use and apply.

15.2.3 Protection Through Contract Law

Many countries and communities opt for protection through contract laws whereby co-operation agreements are established with developing country governments and indigenous communities prior to obtaining biotechnological samples and utilizing associated TK. This allows for profit sharing from any commercial product derived from the biotechnological material with the indigenous communities.

15.2.3.1 Knowledge Registries and Databases

It is important to document knowledge, so that it can be used as a reference against contentious claims, most usually patent claims, and thus prove prior existence of the knowledge. Furthermore, this encourages everyone who uses this knowledge to give some form of acknowledgement to the indigenous knowledge custodians (Kuhnlein et al. 2004).

15.3 Strengthening Science–Policy Interface in Research and Development

15.3.1 Science–Policy Interface

Food security is influenced by policies concerning the management of the environment, in general, and agricultural biodiversity, specifically.

In order to develop interest and participation of all stakeholders in the production, value adding and marketing of *climate smart emerging crops*, it is important to forge strategic partnerships for a joint action or science–policy interactions (Mogotsi and Mogopodi 2019). African governments should incorporate and facilitate (create conducive environment) science–policy interactions and be inclusive in policy decision-making.

The understanding of science–policy interface for the purpose of the discussion is covered under two scenarios as follows:

An interaction between scientists and policy-makers to enhance science-based policy/decision-making and development of policy-relevant to scientific research facilitated by government, individuals and other science–policy interactions practitioners including communities (Wang et al. 2019).

A social process which encompasses relations between scientists and other actors in the policy process and which allows for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making (Van Den Hove 2007).

Therefore, the study on some of the science–policy interactions issues in Botswana are as follows:

Policy Development Ministry of Agricultural Development and Food Security should provide the leadership for development of policy for research, domestication and commercialization of *climate smart emerging crops* in Botswana in collaboration with Ministry of Environment, Natural Resources and Tourism, Ministry of Investment Trade and Industry, and Ministry of Lands and Sanitation Food and Agriculture Organization, and Southern African Development Commission. Botswana Institute for Development Policy Analysis should provide advice, supported by Botswana University of Agriculture and Natural Resources, University of Botswana and Botswana International University of Science and Technology, National Food Technology and Research Centre and Local Enterprise Authority. Community Trusts, farmers and Farmers Associations should continue to play the advocacy role.

Funding Citizen Entrepreneurial Development in collaboration with Food and Agriculture Organization and Southern African Development Commission have been called to mobilize funding for research, domestication and commercialization of *climate smart emerging crops* in Botswana.

Capacity Building Botswana University of Agriculture and Natural Resources, University of Botswana, Botswana International University of Science and Technology, Ministry of Agricultural Development and Food Security, Ministry of Environment, Natural Resources and Tourism, Ministry of Tertiary Education Science and Technology, Ministry of Basic Education, Religious Organizations, Innovation Hub, Farmers Association, National Food Technology and Research Centre, and Local Enterprise Authority have been called to provide *capacity building* in research.

Research and Development Botswana University of Agriculture and Natural Resources, University of Botswana, Botswana International University of Science and Technology, National Food Technology and Research Centre, Ministry of Agricultural Development and Food Security, Ministry of Environment, Natural Resources and Tourism, Ministry of Tertiary Education Science and Technology, Innovation Hub in collaboration with Food and Agriculture Organization to conduct research and development on *climate smart emerging crops*.

Extension Services Ministry of Agricultural Development and Food Security, Ministry of Environment, Natural Resources and Tourism and to some extend Botswana University of Agriculture and Natural Resources (BUAN) are entitled to carry out extension services for *climate smart emerging crops*.

Value Adding Botswana University of Agriculture and Natural Resources and National Food Technology and Research Centre play a key role in value adding of *climate smart emerging crops*.

Export Market Botswana Investment and Trade Centre, Food and Agriculture Organization, Botswana University of Agriculture and Natural Resources and Farmers Associations play key roles in the export market of *climate smart emerging crops*.

Value Chain Botswana Investment and Trade Centre *and Department of Transport have been called to lead in value chain development* for *climate smart emerging crops.*

15.3.2 Science–Policy Interactions Recommendations

Figure 15.5 demonstrates what can be done in order to strengthen science–policy interface in research and development with focus on medicinal plants, but the principle can somewhat be applied to all the other *climate smart emerging crops.* General recommendations for science–policy interactions are given as follows.

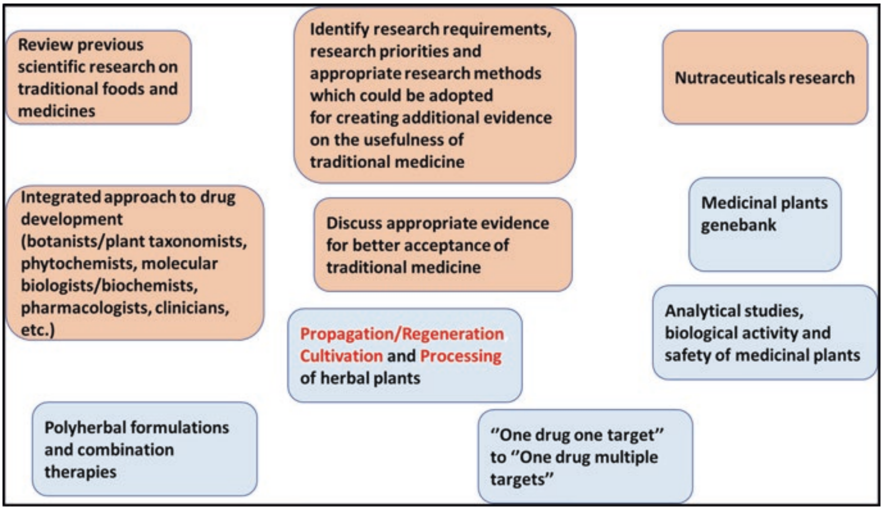

Fig. 15.5 Strengthening science–policy interface in research and development with a focus on indigenous plants and their medicinal properties

15.3.2.1 Promote Domestication, Production, Commercialization and Conservation of Climate Smart Emerging Crops as Expressed in NDP II, Vision 2036 and UN Agenda 2030

Indigenous plant resources have the potential to contribute to the country's objectives of economic and crop diversification. For this potential to be realized, Botswana needs to mainstream natural products research in the country's R & D programmes. This is in line with national and regional policies as expressed in Botswana's NDP11 and Vision 2036 and UN's Agenda 2030 for Sustainable Development. As espoused in these policies, this would further contribute to alleviation of malnutrition and poverty, biodiversity conservation, adaptation to climate change and sustainable agricultural development. This research has shown that *climate smart emerging crops* have potential for domestication, and therefore should be prioritized for domestication and commercialization in Botswana. The Ministry of Agricultural Development and Food Security should initiate the process.

15.3.2.2 Establish Value Chain for Climate Smart Emerging Crops in Consultation with Knowledge Holders and Indigenous Users as They Have Indigenous Belief Systems on the Extraction and Utilization of the Resources

Communities where *climate smart emerging crops* are found are highly knowledgeable about collection methods, conservation strategies, uses and traditional beliefs. Currently, beans and nuts are not sold in formal markets. The Ministry of Agricultural

Development and Food Security in collaboration with communities should conduct a detailed study on the marketing of *climate smart emerging crops*, with the view to establishing value chains and to further ensure that collectors' incomes are improved. This initiative should also consider development of collection points and processing facilities in the ecological areas and a national resource and trading centre for the species.

15.3.2.3 Promote Climate Smart Emerging Crops Community Enterprises Championed by Women and Youth

The majority of collectors, processors and traders of *climate smart emerging crops* are women, who are also the custodians of indigenous knowledge. Department of Agribusiness, Ministry of Agricultural Development and Food Security should therefore engage communities with the view to developing local women and youth enterprises to further promote collaboration among these groups. It is necessary for public policies to apply the gender lens as well, to include traditional communities in order to ensure their participation, and thus achieve the Sustainable Development Goals.

15.3.2.4 Establish a Robust and Cost-Effective Inventory on Climate Smart Emerging Crops to Provide Information on Distribution, Abundance and Potential Risks or Threats

Climate smart emerging crops are still collected from the wild where they are also consumed by wildlife (animals) and freely grazed by livestock. To be able to collect and process these plants for both local and international markets, there should be a well-developed supply chain. Therefore, there should be information on availability and demand of seeds at any given time. In order to achieve this, the Department of Forestry and Range Resources should conduct an inventory and resources-mapping exercise to further establish databases on these products.

15.3.2.5 Support Interdisciplinary Research Teams and Promote Multi-Stakeholder Processes to Enhance the Use of Climate Smart Emerging Crops

Climate smart emerging crops are set to become new crops for Botswana. Research teams covering all relevant disciplines, as well as the stakeholders, should be established to promote research and development, production, marketing and values chain development. BUAN should lead the initiative.

15.3.2.6 Fund Research and Development for Domestication and Commercialization of Climate Smart Emerging Crops for Diversifying Crops Base

In Botswana so far, all efforts towards domestication, commercialization and conservation of *climate smart emerging crops* have been externally funded. This includes the work done by government departments such as seed collection and banking. It is therefore recommended that government departments and institutions of higher learning and research should incorporate natural products in their programmes and fund research and development initiatives related to these plants.

15.3.2.7 Manage Risks in Incorporating Climate Smart Emerging Crops Into the Cropping System in Botswana

Bringing *climate smart emerging crops* into cultivation brings with them some positives and negatives that need to be managed wisely. They may bring specific pests and pathogens that are not yet managed in the agricultural systems. Domestication also brings about vulnerability of the species since they are now required to yield better and to have timely reproductive cycles. These should be researched and managed adequately. The Department of Agricultural Research, BUAN and other stakeholders should conduct research on these.

15.3.2.8 Strengthen the Capacity of Individuals and Institutions in Research, Education and Value Adding of Climate Smart Emerging Crops

Climate smart emerging crops cultivation, value adding, domestication and commercialization is an innovative initiative that will require that Ministry of Tertiary Education Science and Technology support thesis research for both undergraduate and graduate students in all institutions of higher learning in the country on *climate smart emerging crops*. Government should invest in institutional strengthening, retooling of teachers and university, research, development, extension personnel, policy makers, communities and community leadership in all areas towards incorporation of *climate smart emerging crops* into the cropping system of Botswana.

15.4 Plant Description, Uses and Chemical Properties of Selected *Climate Smart Emerging Crops* and Fungi

Climate smart emerging crops and fungi have a great potential for improved incomes, food security and nutrition, combating malnutrition and eradicating poverty. They are adapted to the harsh environment of Botswana and Namibia and linked to traditions, norms and uses. They have been neglected by research, extension, farmers, policy and decision-makers, technology providers and consumers. Non-Governmental organizations (NGOs) at national, regional and international levels started working and discussing the need for research and development of *climate smart emerging crops* also known as 'underutilized', 'neglected', 'orphan', 'minor', 'promising', 'niche' 'traditional' indigenous or lost crops in the 1980s. These were described as having great potential for improved incomes, food security and nutrition and for combating the 'hidden hunger' caused by micronutrients (vitamins and minerals) deficiencies (Jackson et al. 2010). The species were further reported to be strongly linked to the cultural heritage of their places of origin, adapted to specific agro-ecological zones and marginal lands, having traditional uses, neglected by research, extension services, farmers, policy and decision-makers, donors, technology providers and consumers (Jaenicke and Höschle-Zeledon 2006; Jackson et al. 2010). Table 15.3 addresses some the uses provided by the communities in Botswana (Ulian et al. 2014).

*15.4.1 Morama Bean (*Tylosema esculentum *(Burch.) A.Schreib.)*

The Plant

Morama bean is a herbaceous plant with prostrate and trailing stems up to 20 m (Fig. 15.6a, b), occurring naturally in Botswana, Namibia and Republic of South Africa (RSA) grassland and open woodland also associated with dolomitic soils. It is still growing in the wild and cultivation processes is ongoing along the value chain.

Uses of (Tylosema esculentum (Burch.) A.Schreib.)

Young tubers and stems as well as green beans are roasted or boiled and eaten as vegetables. Dry beans are roasted into a snack, boiled with maize meal or ground and pounded to a powder, for making a cocoa-like beverage. The seed and tuber extracts are used in traditional medicine to cure or prevent diarrhoea, headaches, and women's reproductive system problems (Mogotsi and Ulian 2013). The Morama bean plant exctracts have been reported to portray anti-bacterial and anti-viral properties and thus could be included in diets or its flour used as fortified complimentary food product in order to improve the nutritional status of vulnerable populations. The plant extracts have been shown to exhibit broad-spectrum antibacterial activity, mostly harboured in polyphenolic fractions. Thus Morama beans might be an important source of microbicides against the tested bacteria and yeast (Chingwaru et al. 2007).

Value added products are being developed under research and development including morama butter, Morama milk, Morama oil and others (Fig. 15.6c, d). The oil is of good quality and is rich in omega fatty acids; oleic and linoleic acids and has no cholesterol. It is suitable for domestic purposes. The oil extract can be used as a body lotion to prevent itchiness of the skin. Morama bean has also been reported

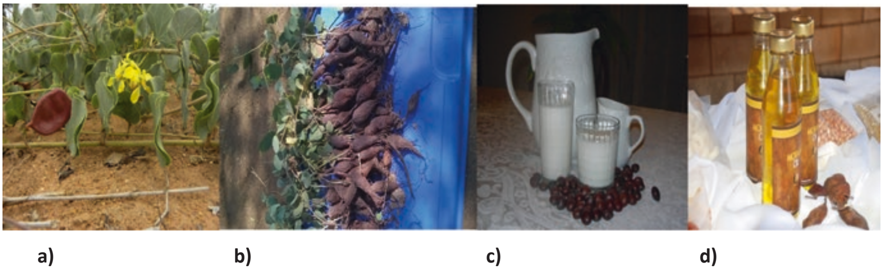

Fig. 15.6 Morama bean plant with (**a**) flower and newly formed pod, (**b**) young tubers, (**c**) milk and (**d**) seeds and oil

to contain nutritionally important antioxidants such as tocopherols, phenolic compounds, trypsin inhibitors, phytates and oligosaccharides, components which have been shown in other foods to contribute to health, in particular, prevention of non-communicable diseases, such as cardiovascular diseases, diabetes and some cancers (Jackson et al. 2010). Multipurpose Tswana chicken feed was also fortified with Morama as source of protein. The feed was found to be comparable to that of fortified bambara ground nut and soy meal and concluded that Morama bean may replace soy bean in chicken feed as source of protein (Manyeula et al. 2018, 2019).

Chemical Properties

The immature Morama beans contain 66.8% moisture, 2.2% ash, 20.8% protein, 1.5% fat and 8.6% carbohydrate (Mosele et al. 2011). The mature Morama bean contains proteins 36–42% and fat 30–32% and is rich in micronutrients and phenolic acids (Mogotsi et al. 2019; Jackson et al. 2010; Mosele et al. 2011; Lekalake et al. 2014). Fatty acids profile are total saturated oils 25.4%, total monounsaturated 46.9% (43% oleic) and total polyunsaturated 27.5% (linoleic).

*15.4.2 Mungongo (*Schinziophyton rautanenii *(Schinz) Radcl.-Sm.*

The Plant

Dioecious tree up to ca. 20 m tall, with a rounded or spreading crown and a trunk up to 1 m in diameter. The bark is whitish, pale grey or pale brown, smooth in young branches, later coming loose. Bears ovoid-ellipsoid drupes up to 70 mm long and 50 mm in diameter. The fruits are light green, covered with velvety hairs, turning yellow when ripe bearing a nut that is rich in oil. The tree grows in Angola, Botswana, DR Congo, Namibia, Tanzania and South Africa (Graz 2007; Chidumayo 2016; Mogotsi et al. 2019).

Uses

The twigs are rubbed together to light fire; branches and younger trees are used as timber; tree trunk is used for fishing floats and for building crates and coffins. The fruit is part of the staple diet in some San communities of northern Botswana and Namibia. The fruit pulp is eaten raw or cooked and the flavour is similar to dates, but less sweet. A strong alcoholic distillate, wine and fresh juice are also made from the pulp due to its high sugar content. The fruits and nuts are available all year, sometimes having the unripe, ripe fruits (as shown in Fig. 15.7a, b) on the same tree as well as nuts (as shown in Fig. 15.7c) for more than 2 years under the same tree. The fruit is eaten fresh and dried and is soaked in water and cooked and the pulp is eaten as a porridge. The oil (as shown Fig. 15.7d) is used for cooking; mixed with meat or added to other traditional relishes by local communities in northern Botswana and Namibia as part of staples. In traditional medicine, the bark is used to cure stomach ache and diarrhoea, the roots are used as a remedy for stomach pains, the oil is used as a body rub in the dry winter months to nourish and moisten the skin (Ulian et al. 2014). In an effort to commercialize the product, the oil is used in soap makings, varnishes, cosmetics, linoleum and oilcloth industry. The highly unsaturated oil may also serve well as paint medium for varnishing purposes (Graz 2007). It also has the potential of biodiesel that is comparable in performance and emission characteristics to that of petroleum and diesel (Chidumayo 2016).

Schinziophyton rautanenii products are traded in informal markets in Malawi, Mozambique, Zambia and Zimbabwe, while oil extracted from the species is exploited commercially in Zimbabwe (Chivandi et al. 2008). In Zambia, the wood and timber obtained from the species is used in producing curios and other crafts that are marketed in tourist resorts (Chidumayo 2016); communities in Kweneng West, Central District and Ngamiland in Botswana have started adding value to mungongo (Mogotsi et al. 2019).

Chemical Properties

The fruit pulp (100 g edible portion) contains water 13.4 g, energy 1307 kJ (312 kcal), protein 6.6 g, fat 0.6 g, carbohydrate 70.2 g, fibre 3.5 g, Ca 89.6 mg, Mg 195 mg, P 46.0 mg, Fe 0.7 mg, Zn 1.4 mg, thiamine 0.28 mg, riboflavin 0.11 mg,

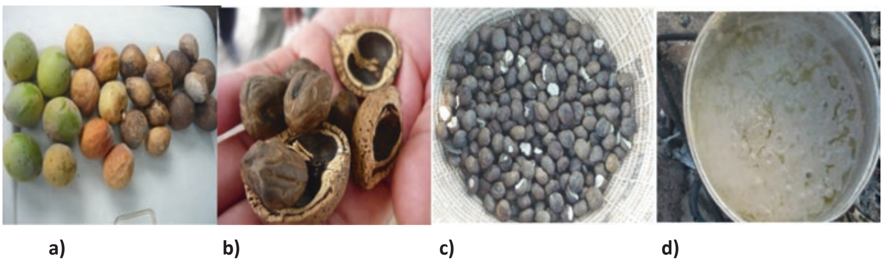

Fig. 15.7 Non-wood products of mungongo (*Schinziophyton rautanenii*) as used by communities in Botswana: (**a**) unripe, ripe fruits and seeds (**b**) nut cover & kernel (**c**) nut (**d**) oil extracted from the nut by traditional method

niacin 0.12 mg, ascorbic acid 8.5 mg. The kernel contains water 4.8 g, energy 2685 kJ (641 kcal), protein 28.8 g, fat 57.3 g, carbohydrate 2.4 g, fibre 2.7 g, P 839 mg, niacin 0.42 mg and 193 mg Ca, 527 mg Mg, 3.7 mg Fe, 2.8 mg Cu, 4 mg Zn, 0.3 mg thiamine, 0.2 mg riboflavin, 0.3 mg nicotinic acid, 565 mg vitamin E (Graz 2007; Mogotsi et al. 2019). Mungongo seed oil (100 g) has been reported to contain elaeostearic acid (18:3) (25%), linoleic acid (18:2) (37%), oleic acid (18:1) (15%), palmitic and stearic acid (18:0) (8–9%), respectively (Juliani et al. 2007).

*15.4.3 Morula (*Sclerocarya birrea *Subsp. Caffra (Sond.) Kokwaro)*

The Plant

A thick-boled laxly branched tree up to 18 m tall, with a widely reticulate, greyish bark and spreading branches. The male flowers have sepals ca. 2 mm long and broad and petals yellow to purplish-pink (red in bud), female inflorescences subterminal and shorter than the male ones and with fewer flowers; axis and pedicels thickened in the fruiting state (Ngwako et al. 2019).

Fruits are fleshy drupes, yellow, 3–3.5 cm in diameter, with very juicy mesocarp. Stones are thick and obovoid 2.3 × 2.5 cm, with one to four cavities each containing a seed (Mojeremane and Tshwenyane 2004; Moyo et al. 2009). Morula tree is found in Swaziland, Mozambique, Zimbabwe, Botswana and Namibia (Van Wyk 2008). In Botswana, it is spread throughout the country, except from the deep sand areas of the Kgalagadi (Roodt 1998).

Uses

The fruits that are rich in Vitamin C are edible and can be eaten fresh or made into a delicious jelly, jam, leather or candy. They are also used to make traditional non-alcoholic and alcoholic beers and wines including the popular commercial alcoholic amarula liqueur (van Wyk and van Wyk 1997). The juice can be used to flavour cereals and kernel used in confectionary industry or fortification of bread products (Hall 2002). Game eat the fruits lying on the ground or from the tree in case of the elephants (Jøker and Erdey 2003). Seeds are also edible, and they can be eaten raw; they are rich in oil, protein, vitamins. especially vitamin C and minerals. The oil is used to preserve meat; cooking and skin care (Moyo et al. 2009). The bark is used for medicinal purposes such as the treatment of dysentery and diarrhoea and also to prevent malaria (Jøker and Erdey 2003). The wood is used for making household materials (pestles, mortars, bowls, saddles, furniture and fencing) (Ngwako et al. 2019). The leaves, barks and roots are used to treat infections and parasitic diseases, problems with the digestive tract and injuries, diarrhoea and dysentery, stomach ailments, diabetes, fever and ulcers, sore eyes. The bark is used to produce a mauve, pink, brown or red dye, the colour as well as the production of ink by dissolving gum from the bark in water and adding soot (Hall 2002).

Chemical Properties

The fruit skin, pulp and the juice are rich in ascorbic acid 150–250 mg, 150–400 mg and 100–200 mg/100 g, respectively. The edible 100 g portion of the kernels contains protein 20–35%, fat 55–65 g%, phosphorus 0.7–1.9% and an energy value of 25 MJ/kg. The fatty acids profile for 100 g of the oil is oleic acid 64–74.5%, palmitic acid 11–17.5%, stearic acid 5–11% and linoleic acid 4–9%. The kernel is also rich in amino acids glutamic acid as 18–27%, arginine 11–16% and aspartic acid 5.5–8% for 100 g proteins (Hall 2002).

*15.4.4 Mosukujane (*Lippia javanica *(Burm.f.) Spreng)*

The Plant

An erect perennial woody multi-stemmed woody shrub. Leaves are strongly aromatic when crushed. The plant is found in woodlands and wooded grasslands, riverine vegetation, swampy ground margins, disturbed and cultivated. It is found in Botswana, South Africa, Swaziland, Mozambique, Malawi, Tanzania, Zambia, Zimbabwe, Tanzania, Uganda and Kenya and Ethiopia (Tshwenyane et al. 2019; Maroyi 2017).

Uses

Leaves and twigs of *Lippia javanica* are used as food additives in Kenya and is popular as herbal tea in Botswana, South Africa and Zimbabwe. Different parts of the plant are used to give a calming and relaxing effect and to treat asthma, coughs, colds, fever, bronchitis, malaria, influenza, pneumonia, tuberculosis and topically for scabies, measles and lice (Maroyi 2017; Tshwenyane et al. 2019). The essential oil shows moderate antibacterial activity against pathogens and promising anti-inflammatory activity. The volatile oil could have a commercial value. Herbal teas of this species have been produced and packaged for sale in shops and pharmacies in Botswana and for export by a non-governmental organization called Thusano Lefatsheng since the early 1990s. Informal trade also happens in major villages, cities and towns as a perfume, as an insect repellent, and its possible use to control bark beetles of the genus IPs is being investigated (Tshwenyane et al. 2019)

Chemical Properties

Studies have revealed that the plant is rich in caryophyllene, carvone, ipsenone, ipsdienone, limonene, linalool, myrcene, myrcenone, ocimenone, p-cymene, piperitenone, sabinene and tagetenone. These essential oil profiles have been reported to be myrcenone-rich type (36–62%), carvone-rich type (61–73%), piperitenone (32–48%), ipsdienone-rich type (42–61%) and linalool-rich type (>65%) (Maroyi 2017).

*15.4.5 Moringa (*Moringa oleifera *Lam.)*

The Plant

Moringa oleifera Lam. commonly referred to as Moringa is a single family of shrubs and trees, which is most widely cultivated and studied variety. A native of the sub-Himalayan regions of north-west India, but now introduced to many tropical countries in Africa, Arabia, South East Asia, the Pacific and Caribbean Islands and South America. Commonly known as the 'horse-radish' tree (arising from the taste of a condiment prepared from the roots) or 'drumstick' tree (arising from the shape of the pods), Moringa has a host of other country-specific vernacular names (*zogale* in northern Nigeria, *zakalanda* in Zambia and Zimbabwe, *shagara al ruwag* in Sudan, etc.), an indication of the significance of the tree around the world. Different Moringa species include *M. arborea, M. borziana, M. concanensis, M. drouhardii, M. hildebrandtii, M. longituba, M. oleifera (syn. M. pterygosperma), M. ovalifolia, M. peregrine, M. pygmaea, M. rivae, M. ruspoliana and M. stenopetala*.

Uses

Many consider Moringa to be a miracle tree because every part of the tree is utilized in some form or the other. Moringa is thus exploited in many applications such as food, medicine, biofuels and fodder. However, for any of these applications to be commercially successful, sustainable and localized cultivation and processing are pre-requisites. Some of the uses and potential uses of the non-woody leaves and seeds are discussed, and their uses are shown in Fig. 15.8. Leaves, seeds and pods

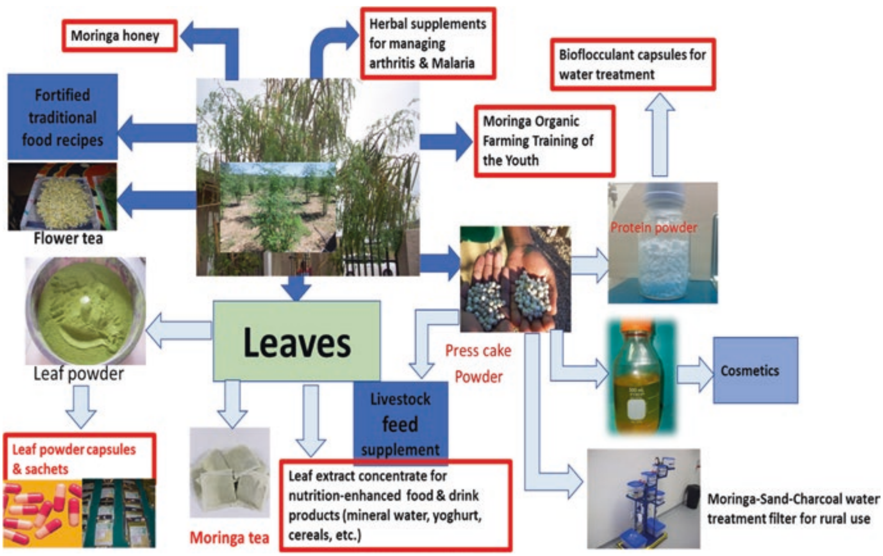

Fig. 15.8 Uses and the potential uses of Moringa leaves and seeds (Kwaambwa et al. 2021, Unpublished)

are the main parts that can be used as food or food supplements as a source of food especially during global crisis COVID-19 and supplement for medicine.

M. oleifera has been used to fortify processed foods and has been shown to increase their nutritional value, organoleptic properties, oxidative stability and product shelf life (Falowo et al. 2018). However, very few studies have been done with regard to the toxicity, nutrient bioavailability and efficacy of *M. oleifera* (Falowo et al. 2018). Thus, research in these areas is required in order to promote utilization of *M. oleifera*. *M. oleifera* is used extensively and broadly in a number of ailments, most of which have been tested pharmacologically and clinically in various mechanistic and animal models. This enormous medicinal potential has long been recognized (Farooq et al. 2012). It is rich in proteins, vitamin A, minerals, essential amino acids, antioxidants, and flavonoids, as well as isothiocyanates. The extracts from *M. oleifera* exhibit multiple nutraceutical or pharmacological functions including anti-inflammatory, antioxidant, anti-cancer, cardiac and circulatory stimulant, hepatoprotective, neuroprotective, analgesic activity, hypoglycemic, antimicrobial activity, anticholesterol activity, anti-diabetes activity, antibacterial activity and blood lipid-reducing functions (Dixit et al. 2016). The beneficial effects of *M. oleifera* are strongly associated with its phytochemicals such as flavonoids or isothiocyanates with bioactivity. It is thus outside the scope of this review to exhaustively discuss this extensive list of studies done on *M. oleifera* extracts, but we thus limited our discussion to highlighting a selected few medicinal properties of the leaf extracts.

Moringa seeds are used to extract oil called the Ben oil. This oil is rich in oleic acid, tocopherols and sterols. It can also withstand oxidative rancidity. Oil from the seeds of the tree can contain 1–2% of beneficial essential fatty acids such as omega 3 and omega 6. The oil can be used for cooking as well as a lubricant in fine machinery and biodiesel and in the manufacture of cosmetics such as soaps, perfume and hair care products. High in antioxidants, the tea made from Moringa has been used to combat malnutrition in many parts of the world. While the Moringa seeds can be used in cosmetics and also are sources of biodiesel, the seedcakes can be used as a green manure or a fertilizer or for water treatment. The seeds and seed cake are an effective primary coagulant in water treatment as they have the capacity to remove up to 99% of bacteria from water. Fresh Moringa leaves can be cooked and eaten as vegetables or processed into tea, powder and other pharmaceutical preparations such capsules (Gopalakrishnan et al. 2016).

The growth hormone from the leaves, called Zeatin, is an excellent foliar and can increase the crop yield by 25–30%. Incorporation and fortification of Moringa can be significant to tackle nutrient deficiencies and malnutrition. Several food materials such snacks, cereals and yogurts are currently being fortified with Moringa leaf powder or extracts to improve the nutritional composition. Owusu et al. (2011) also used Moringa as a fortificant and produced cream and butter crackers with Moringa. *M. oleifera* leaves can be incorporated in the diet of hens and layers thereby providing excellent protein source, substituting other expensive ingredients such as soybean meal and ground nut cake. Considering the views of several such fortifications, it is suggested that such addition can be done to other snacks as well. Addition of

Moringa to the snacks can add nutritive value to the snacks. Most snacks are made up of corn meal, and several studies demonstrated that a little addition of Moringa to maize flour could add nutritive value to the snack in terms of protein, energy and minerals. However, further studies on Moringa, as a fortified Indian snack is required before bringing commercialized Moringa to the market.

Chemical Properties

Fresh leaves contain proteins 5–7 g, energy 92 cal, carbohydrates 13.4 g, Fat 1.70, fibre 0.90, oxalic acid 101 mg, calcium 350–550 mg, potassium 200–500 mg, magnesium 80–120 mg, phosphorus 50–120 mg, iron 0.7–8 mg, manganese 1.2–2.5 mg, zinc 0.4–0.6 mg, copper 0.2–1.1 mg, sulphur 137 mg, vitamin C 120–220 mg, vitamin A 1500–4000 μg eq. retinol, vitamin B1 (Thiamin) 0.06 mg, vitamin B2 (Riboflavin 0.05 mg, Vitamin B3 (niacin) 0.8 mg, Vitamin E (as Vitamin E as α tocopherol) 150–200 mg. Dry powder contains proteins 20–27 g, carbohydrates 38.2, fat 2.30 g, fibre 19.2 g, calcium (Ca) 1600–2200 mg, potassium 800–1800 mg, magnesium 350–500 mg, phosphorus 200–600 mg, iron 18–28 mg, manganese 5–9 mg, zinc 1.5–3 mg, copper 0.7–1.1 mg, sulphur 870 mg, vitamin C 15–100 mg, vitamin A (β Carotene) 4000–8000 μg eq. retinol, vitamin B1 (Thiamin) 2.64 mg. vitamin B2 (Riboflavin) 20.5 mg, vitamin B3 (Niacin) 8.2 mg, vitamin E (as α-tocopherol) 80–150 mg.

*15.4.6 Kgengwe (*Citrullus lanatus *(Thunb.) Matsum. & Nakai)*

The Plant

Annual herb and climber with prostrate stems and forked tendrils belonging to *Cucurbitaceae*, native of the western Kalahari region where it is still found in the wild. Nowadays, it is spread throughout the African continent due to domestication and cultivation that started more than 4000 years ago. In Botswana, it is mostly found in the lower and western parts of the country. It prefers deep sands such those of the Kalahari. It was also introduced in China, eastern Asia, Malaysia, the Indian subcontinent, Australia, South America and North America where it is still cultivated or naturalized (Setshogo and Hargreaves 2002; Mogotsi et al. 2019).

Uses

The succulent fruits (Fig. 15.9) are used as a water source during hunting or when far from conventional water sources, since its spread, most stock help itself to the abundant water in it, especially during drought or extreme heat which are frequent in the Kalahari (Fig. 15.9). Laboratory results showed that 95% of the water content remained 7 months after abscission. The pulp can also be sliced and sun dried or cooked and mixed with maize meal to create a porridge served with creamy milk. A sweet jam is also prepared. Seeds are roasted and eaten or are dried and pounded into flour to make a kind of bread. Seeds may prove a useful source of protein and

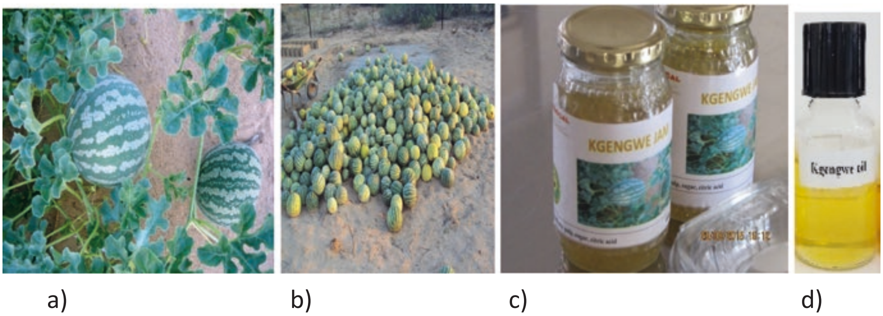

Fig. 15.9 (**a**) Plant and melon (**b**) melons for processing (**c**) kgengwe jam (**d**) kgengwe seed oil

fat for sub-Saharan and savannah populations. Traditionally, Namibian women extract seed oil for a variety of household purposes. It is considered a good substitute for cottonseed oil. In southern Africa, the species is often cultivated as an intercalary crop with maize and kaffir corn in tribal gardens. These cultivated forms show a high yield even in drought years (Setshogo and Hargreaves 2002).

*15.4.7 Mahupu (***Kalaharituber pfeilii** *Trappe)*

Plant Description

Truffles are edibles hypogeous fruit bodies produced by fungi belonging to the class Ascomycetes. The mature Kalahari truffles are up to 12 cm in diameter normally with pale brown outer periderm and interior whitish pockets of spore-bearing tissue separated by pale brownish veins Fig. 15.10 (Khonga et al. 2005). They weigh up to 500 g with differences being related to the amount of rain received (Taylor et al. 1996; Trappe et al. 2008). They are round, more or less spherical to turbinate (Fig. 15.10), thick-walled and solid. The fruit bodies are carried up on a stalk composed of entangled hyphae and sand particles. The bottom of the stalk, which is between 2 and 10 cm in length, is connected to rhizomorphs and to hyphae emanating from adjacent roots of various trees and grasses in Kgalagadi and Namib deserts. The rhizomorphs lead from colonized roots to the fruit body, which may lie as much as 40 cm away (Taylor et al. 1996). Occur in the Kalahari Desert: Namibia, Botswana and South Africa (Khonga et al. 2005). Arid and semiarid areas of the Kalahari Desert alongside other desert species as *Tylosema* sp., *Citrullus* sp., *Acacia hebecladas*, *A. mellifera*, *Boscia albitrunca*, *Grewia flava* and *Stipagrostis uniplumis and Acasia* sp. (Trappe et al. 2008). It can also be found in cultivated fields of various food crops (Khonga et al. 2005; Mogotsi et al. 2019).

Uses

The truffles are eaten raw or cooked (Fig. 15.3); boiled, roasted over fire or buried in hot ashes (Trappe et al. 2008). They constitute an important element in the diet of the desert dwellers (Ackerman et al. 1975; Sawaya et al. 1985) as they are highly nutritious with higher protein, fat, fibre, magnesium, potassium and phosphate

Fig. 15.10 (**a**) Fruiting body with hyphae (**b**) truffle for marketing (**c**) processing by sun drying (**d**) sundried truffles. (*Source*: Mogotsi et al. 2019)

Table 15.4 Selected fatty acids profile of the Kgalagadi desert truffle

Fatty acid	Molecular mass (g)	Intensity
Pentadesilic pentanedioc	132.12	162.12
Stearic/octadecanoic	283.5	314.48
Oleic acid	281.5	312.4
Linoleic acid	279.5	310.45
Linolenic α	277.4	308.43
Linolenic γ	278.43	308.43

Source: Bogopa (2013)

concentrations than many other vegetables (Kasterine and Hughes 2012). They also have good antioxidant proprieties and are considered aphrodisiacs. Sorghum and watermelon showed a higher growth rate when grown in sand enriched with various concentrations of truffles (Trappe et al. 2008).

Chemical Properties

The nutritional composition of desert truffles has determined and the fruiting body has been found to contain 20–27% protein, some 85% of which is digestible by humans; 3–7.5% fat, including unsaturated as well as saturated fatty acids; 7–13% crude fibre; close to 60% carbohydrates; and appreciable amounts (2–5%) of ascorbic acid (Murcia et al. 2003). Truffles also contain 17.7% oil: 37.18%, saturated fatty acids and 62.82% unsaturated fatty acid. They contain both essential and non-essential amino acids and contain mainly fatty acid methyl esters and unsaturated aliphatic hydrocarbons. A total of 24 volatile compounds with a molecular weight range from 110 to 354. A total of 16 amino acids have been identified while 17 fatty acids (MW from 132.12 to 367.49) were also identified including oleic acid, linked with a reduction in the risk of coronary heart disease as well as stearic acid in the diet, which is known to have favourable effects on thrombogenic and atherogenic risk factors in males; other identified fatty acids are as outlined Table 15.4 (Bogopa 2013). The dry matter (about 20% by weight) consists of: 20–27% protein, some 85% of which is digestible by humans; 3–7.5% fat, including unsaturated as well as saturated fatty acids; 7–13% crude fiber; close to 60% carbohydrates; and appreciable amounts (2–5%) of ascorbic acid (Murcia et al. 2003)

15.5 Conclusion

Given medicinal, nutritional and chemical properties of these *climate smart emerging crops,* these food plants can contribute towards providing nutrient requirements and medicinal properties shown in Table 15.1. The data on the composition of these *climate smart emerging crops*, with regard to proximate analysis, minerals, fatty acids and amino acids and as a source of antioxidants, demonstrate that these are a source of high quality food and their cultivation could prove more valuable than some of the established crops as a source of protein, minerals, carbohydrates, fat and amino acids, fatty acids and antioxidants in the diet of human beings. Thus, these plants have the potential to contribute to food security. It is essential that scientists, policy makers and implementers should develop clear platform of communication in order to enhance science-based policy/decision-making and development for research and development of *climate smart emerging crops*. African governments should incorporate and facilitate (create conducive environment) for science–policy interactions and be inclusive in policy decision-making. This could ensure that the potential economic benefits of these plants are fully harnessed.

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Chapter 16
Essentials of Nutraceuticals and Probiotics

Nneka R. Agbakoba

16.1 Introduction

Food can be described as any substance that can be consumed by living organisms in order to sustain life. Much as it is necessary to sustain life, one should consume food that is nourishing as well. In the days of our forefathers, traditional foods obtained from their farms and animals bred in their homes were mostly the foods they consumed. In recent times, however, new lifestyles have been adopted because of strenuous work schedules, longer working hours, and urbanization; all of which made people not to have time to cook their own meals. This has changed the basic food habits of people. They would rather resort to eating various junk food, fast food, as well as patronize all sorts of roadside food vendors. These meals may be tasty but the quantity and quality of nutrients they contain are usually very poor (Prabu et al. 2012a). Likewise, the use of various chemicals, heavy metals, electromagnetic waves, and other potentially harmful man-made items as a result of industrialization has caused air and water pollution, as well as soil and food contamination. These problems have led to an increased incidence of various disease conditions like diabetes, obesity, cancers, vascular diseases, physiological problems, as well as other degenerative diseases leading to severe immune dysfunction (Prabu et al. 2012a).

Humans should be mindful of what they consume. Getting adequate nutrients from food should be key in maintaining normal function of the human body. Recently, natural products and health-promoting foods have been receiving attention from both health professionals and the public. With this, concepts such as nutraceuticals and nutritional therapy are now available (Bland 1996). According to

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the popular saying of Hippocrates (460–377 BC), "let food be thy medicine and medicine thy food"; this is where nutraceutical foods come in. These are foods that can be described as "a food or parts of food that provide medical or health benefits, including the prevention and treatment of disease" (Prabu et al. 2012b).

While nutraceuticals are food with extra health benefits, the additional benefits of the deliberate inclusion of certain microorganisms in foods have gained recognition, leading to the increased availability and popularity of probiotic foods. Probiotics are described as live microorganisms which, when administered to a host in adequate amounts, confer health benefits on the host (WHO 2002). Such microorganisms are deliberately included in foods or can be administered as supplements (Anukam et al. 2020; Onwuliri et al. 2021).

16.2 Nutraceuticals

The word "nutraceutical" was coined from the combination of two words—"nutrient" and "pharmaceutical" by Stephen De Felice (DeFelice 1993) founder and chairman of the Foundation for Innovation in Medicine (FIM), Cranford, NJ, in 1989 (Maddi et al. 2007). It simply means a nourishing food that can also serve as medicine. They are also called "bioceuticals." In addition to the basic nutritional value found in foods, there is need to also consume food that have extra health benefits. Nutraceuticals can be said to be nonspecific biological therapies used in promoting general well-being of humans. The basic difference between nutraceuticals and functional foods is that a functional food has been defined as being similar in appearance to conventional foods and consumed as part of a usual diet, whereas a nutraceutical is a food product sold in forms like pills, powders, and other medicinal forms not usually associated with food. Simply put, nutraceutical is any food or food ingredient considered to provide medical or health benefits including the prevention and treatment of disease while functional food is one that has a specific component incorporated into it that gives it a specific physiological or medical benefit that is beside the original nutritional benefit. Hence, it can be stated that a functional food is actually a food, while a nutraceutical is actually a separate entity in concentrated form. Nutraceuticals and functional foods play roles in health, as well as in disease therapy and prevention and so they can be said to be half way between food and drug.

Nutraceuticals, also known as medical foods and nutritional supplements, include everyday products as "bio" yogurts and fortified breakfast cereals, as well as vitamins, whole foods, food additives, herbs, phytonutrients, probiotics, minerals, herbal products, and even genetically modified foods and supplements. They are considered healthy sources for prevention of life threatening diseases such as diabetes, renal and gastrointestinal disorders, as well as different infections. Nutraceuticals are said to focus mainly on preventive rather than on curative therapy and products have been claimed to provide various health benefits, such as preventing chronic diseases, delaying aging process, and by extension, increasing life expectancy.

Nutraceuticals are concentrated and sold in form of capsules, powders, and tinctures and may come as a single substance or combined with other preparations (Stephen 1998). They can come from plants, animals, and microbial sources.

Some commonly used nutraceuticals include the following:

(i) Vitamin B12 This water-soluble vitamin occurs naturally in foods such as beef, tuna, and dairy products. It is usually taken by people as a dietary supplement to maintain healthy nerves, aid in the production of red blood cells, and to increase energy levels.

(ii) Green Tea This extract is one of the most powerful and popular herbal extracts in the world. A strong antioxidant, imparts vitamins and nutrients that slow down the aging process and protects the skin from oxidative stress and environmental damage.

(iii) Ginseng This has for long been used to purify and nourish the skin, balance the gastrointestinal tract, regulate appetite, increase circulation, decrease stress, balance the central and peripheral nervous systems, and stabilize blood sugar. It also acts as a natural energizer.

(iv) Fish Fish contains various nutrients like omega-3 fatty acids, which have potentially favorable effects on health. People who take fish and fish oil supplements have a lower rate of CVD.

(v) Fruits and Vegetables Inadequate consumption of fruit and vegetables has been linked with higher incidence of CVD. Susceptibility of LDL particles to oxidation have been found to be reduced by fruits and vegetables. Some bioactive components like carotenoids, fiber, magnesium, potassium, and vitamin C that are present in fruits and vegetables act either synergistically or antagonistically to promote a beneficial effect.

(vi) Nuts and Legumes Nuts are complex foods containing cholesterol lowering mono- and polyunsaturated fatty acids, arginine, soluble fiber, and several antioxidant polyphenols. Legumes are also rich in soluble fibers and polyphenols, as well as vitamin C.

(vii) Glucosamine this amino sugar plays a significant role in building cartilage in the body. Glucosamine occurs naturally around the joints and in bone marrow. Some people take glucosamine supplement to treat arthritis and joint pain.

(viii) Fennel Fennel is an herb used for cooking. It has both antioxidant and anti-inflammatory properties that gives it powerful health benefits. It is packed with vitamins and minerals, and when taken as a dietary supplement, it acts as a natural appetite suppressant.

(ix) Dietary Polyphenols This is useful in the treatment of diabetes. It has been reported that due to the biological properties of plant-foods polyphenols, they may be unique nutraceuticals and supplementary treatments for various aspects of type 2 diabetes mellitus. Polyphenolic compounds can also prevent the development of long-term diabetes complications, such as retinopathy, cardiovascular disease, neuropathy, and nephropathy.

(x) Buck Wheat Buckwheat seed proteins have beneficial role in obesity and constipation acting similar to natural fibers present in food. 5-hydroxytryptophan and green tea extract may promote weight loss.

(xi) B-Carotene B-Carotene is the more common form of the carotenes (others are alpha and gamma) and can be found in yellow, orange, and green leafy fruits and vegetables. These can be carrots, spinach, lettuce, tomatoes, sweet potatoes, broccoli, cantaloupe, oranges, and winter squash. Beta-carotene is the main source of vitamin A and has antioxidant properties, which help in preventing cancer and other diseases. Among the other carotenes, beta-carotene is the most active antioxidants. Alpha, beta, and gamma carotenes as well as lycopene seem to offer protection against breast, colorectal, lung, prostate, and uterine cancers.

16.2.1 Classification of Nutraceuticals

The way nutraceuticals are classified vary. On a broad base and on the availability of food in the market, they are classified as traditional and nontraditional nutraceuticals.

Traditional Nutraceuticals These are food consumed as part of regular diet to directly obtain the valuable effects they contain. In traditional food, no change to the food is made. They are simply natural, whole foods with new information about their potential health qualities. Apart from the way the consumers actually perceive the foods, there has been no change to the actual foods. Many dairy and meat products, fruits, fish, grains, and vegetables contain several natural components that deliver benefits beyond basic nutrition. Some of them include the following:

- Lycopene in tomatoes
- Omega-3 fatty acids in salmon, cheese, eggs, and milk
- Saponins in soy

According to Prabu et al. (2012a), some examples of traditional nutraceuticals include the following:

- Customized fatty acids and vegetable oils
- All fruit juices and other drinks that increase the oxidant levels in humans
- Cereals and grains that contain adequate amount of nutritional fiber

- Vegetable proteins which are obtained from legumes, soy, and vegetables

The traditional nutraceuticals are split further based on chemical constituents, nutraceutical enzymes, and probiotic microorganisms.

Chemical Constituents These include the following:

- Nutrients: These are feed constituents required to support the life of humans or animals. The main classes of feed nutrients are carbohydrates, fats, minerals, proteins, and vitamins. Nutrients also include amino acids, animal products (meat, poultry), dairy products, fatty acids, and fruits (Prabu et al. 2012a).
- Herbals: These are botanical products presented as concentrates and extracts. Herbals have been in existence for as long as human civilization, and they have been used for treating acute and chronic diseases. Numerous nutraceuticals are present in medicinal herbs. Examples of some herbs include peppermint, lavender, cranberries (Chauhan et al. 2013).
- Phytochemicals, such as alpha (α), beta (β), and gamma (γ)-carotene, hesperidin, limonene, lutein, lycopene, rutin (Prakash et al. 2012).

Nutraceutical Enzymes These come from various sources like fruits (pineapple), whole grains, beans, broccoli, soybeans, and some higher plants. Examples of nutraceutical enzymes include α-galactosidase (obtained from whole grains, asparagus, beans, broccoli, biodiastase, β-amylase, bromelain, chymotrypsin, oxbile, pectinase) and pepsin (Singh and Sinha 2012).

Probiotic Microorganisms These will be discussed in detail in Sect. 16.6. They belong to various group of microbes that include *Bacillus*, *Bifidobacterium*, *Enterococcus*, *Escherichia coli*, *Lactobacillus*, *Leuconostoc*, *Pediococcus*, *Saccharomyces*, and *Streptococcus* (Fijan 2014).

16.2.2 Nontraditional Nutraceuticals

These are artificially prepared products of plant materials as arranged by agricultural scientists. They come in the form of genetically engineered foods, follow-on added ingredients or agricultural breeding. These artificially prepared nutraceuticals are intended to improve or boost the nutritional content of certain crops, boost animal yields. Examples of nontraditional nutraceutical food include the following:

- Fruit juice fortified with calcium
- Cereals into which vitamins and minerals have been incorporated
- Flour fortified with folic acid

Nutraceuticals are also further grouped into the following categories: functional food, dietary supplements, medicinal food, and farmaceuticals.

(a) Functional Foods This category of nutraceuticals includes whole foods believed to provide health benefits beyond the known nutrients it contains. It usually contains fortified and enriched dietary components capable of lowering the risk of chronic diseases. The dietary components are added during food processing and then sold as providing some benefit to consumers. They are eaten as a part of regular diet to directly obtain the useful effects they contain. Functional food provides the body with the needed amount of carbohydrates, proteins, fats, and vitamins needed for healthy living. When functional food helps in the treatment and/or prevention of disease conditions or disorders other than deficiency conditions like anemia it is called a nutraceutical (Kalra 2003).

(b) Dietary Supplement This is a dietary ingredient added to a food as supplement in order to enhance its dietary values. Dietary supplements are products administered orally that contain a dietary ingredient intended to add value to the foods consumed. Such added dietary ingredients may include vitamins, amino acids, herbs, and enzymes. Dietary supplements can be concentrates, which may come in form of soft gels, capsules, tablets, powder, or liquids. The different regulatory bodies in different countries regulate dietary supplements. It is not supposed to be used to treat, cure, or prevent any disease. Generally, these supplements may only be made to support the structure or function of the body, and so should not claim to treat a disease condition.

(c) Medicinal Food This is made to be taken orally as drugs under a doctor's supervision. It is usually formulated as a supplement to manage a specific disease or condition for which exists a specific or known nutritional need. Medicinal foods are formulations used to take care or manage patients with conditions like inborn errors in amino acid metabolism. Newer medicinal foods are designed to manage other conditions like pancreatic exocrine insufficiency, inflammatory conditions, cancer, and other diseases.

(d) Farmaceuticals These are products containing medically valuable components, and these are produced from herbal/naturally modified agricultural crops or animals.

16.3 Health Benefits of Nutraceuticals

The use of diet for treatment is based on the belief that foods cannot only serve as sources of nutrients and energy but could also provide medicinal benefits. As nutraceuticals have natural dietary supplement, they do not have unpleasant side effect. In addition, they are easily available and economically affordable. Modern lifestyles of people these days—where they are too busy to cook and eat nutritious food; do not have the time to even cultivate vegetable and fruits in their little backyard; are always in a hurry to catch-up with one thing or the other—have led to their eating mostly junk foods. Consumption of fast food and junk food with very poor nutritional values have greatly increased, and this is consequently leading to a rise in the number of diseases and conditions like diabetes, obesity, heart diseases, cancers, arthritis, and a lot more. Eating nutritious and food with health benefits will go a long way to solving some of these health issues. Nutraceuticals have been found to be useful to humans both physiologically and psychologically. Their usefulness is limitless as more uses are discovered on a daily basis. Some of these uses include the following:

- Improvement in overall health
- Boosting energy of users
- Relief in anxiety
- Improvement in mental clarity
- Enhancing sleep quality and quantity
- Preventing chronic diseases
- Reduction in drug cravings
- Delay the aging process
- Increase quality of life
- Regulate bodily functions (Kim 2020)

16.4 Role of Nutraceuticals in Sustaining Human Health (Table 16.1)

In addition to the associated health benefits of nutraceuticals, they have also been found useful in the following disease conditions:

(i) Cardiovascular Diseases Nutraceuticals possessing constituents such as antioxidants, dietary fibers, omega-3 fatty acids, vitamins, and minerals have been found to be useful in the prevention and treatment of cardiovascular diseases (CVD). Corn has been found to be useful in the prevention of heart attack and lung cancer. Corn contains fiber and also supplies significant amount of folate. Corn also contains cryptoxanthin, a natural carotenoid pigment, that can reduce the risk of lung cancer. Others include polyphenol (in grape) which prevents and controls arterial diseases (German and Walzem 2000); and flavonoids (found in apples, cherries, onion, grapes, red wine, and vegetables) which strengthen the tiny oxygen-carrying capillaries that supply oxygen and essential nutrients to all cells (Hollman et al. 1999).

(ii) Obesity Nutraceuticals, such as herbal stimulants (e.g., ephedrine), caffeine, green tea, and chitosan, assist in body weight reduction. The compound, 5-hydroxytryptophan, and green tea extract may promote weight loss. The 5-hydroxytryptophan decreases appetite, while green tea increases the energy expenditure. A mixture of glucomannan, chitosan, fenugreek, and vitamin C in

Table 16.1 Nutraceuticals and their uses

Types	Chemical constituents	Sources	Uses
Carotenoids	Lycopene β-Carotene Lutein Tocotrienol Saponins	Guava, papaya, water melon, tomatoes, pink-colored grape fruit Can be obtained from oats, carrots, fruits, vegetables Spinach, corn, avocado, egg yolk Palm oil, different grains. Beans like soya beans, chickpeas	They help in lowering cholesterol levels, possess antioxidants properties, and protects against cancer Antioxidants, protection of cornea against UV light Protect eyes against cataracts, age-related degeneration, anticancer activity(colon) Helps improve cardio vascular health, protects against cancer (breast cancer) Effective against colon cancer, lowers the levels of cholesterol in humans
Polyphenolic compounds	Flavonones Flavones Flavonols Curcumin Glucosinolates	Citrus fruits Different types of fruits, soya beans, vegetables Broccoli, tea, onions, fruits like apple Turmeric root Cauliflower, cruciferous vegetables	Possess many types of antioxidant and anti-cancer activity Possess many types of antioxidant and anti-cancer activity Antioxidant activity A good anti-clotting agent. Also possess strong anti-inflammatory and antioxidant properties Anticancer activity, protect against bladder cancer
Phyto-estrogens	Isoflavones Lignans	Legumes, beans like soy beans Vegetables, rye, and flaxseed	Antioxidants, lowers LDL cholesterol, protects against prostate, breast, and bowel cancers Protects against development of cancer like colon and breast cancer
Dietary fiber	Soluble fiber Insoluble fiber Sulfides/thi-ols	Legumes, cereals like oats, barley, some fibrous fruits Whole grain foods, wheat and corn bran, nuts, etc. Present in cruciferous vegetables	Helps in maintenance of healthy digestive tracts and possess anti-cancer activity Helps in maintenance of healthy digestive tracts and possess anti-cancer activity Helps in maintenance of healthy immune function

(continued)

Table 16.1 (continued)

Types	Chemical constituents	Sources	Uses
Fatty acids	Omega-3 fatty acids Monosaturated fatty acids Prebiotics/probiotics lactobacilli, bifidobacteria Minerals like zinc, calcium, selenium, copper, potassium Polyols, sugar alcohols (xylitol, sorbitol)	Present in salmon & flax seed Present in tree nuts Present in yogurt, other dairy and nondairy applications Food Present in fruits	Strong controllers of the inflammatory processes, helps in maintenance of brain function, and lowers cholesterol disposition They lower the risk of coronary heart disease. They help to improve gastrointestinal health and systematic immunity. These are the essential constituents of balanced diet They can lower the risk of dental caries (cavities)

Source: Khan et al. (2014)

dietary supplement were reported to significantly reduce body weight (Swaroopa and Srinath 2017). Buckwheat seed proteins act in a way similar to natural fibers present in food and so play beneficial role in obesity and constipation.

(iii) Cancer Beta-carotene is the main source of vitamin A and has antioxidant properties which help in the prevention of cancer and other diseases. Alpha and beta carotenes, along with gamma carotene, lycopene, and lutein 68, seem to offer protection against various types of cancers including breast, colorectal, lung, uterine, and prostate cancers. The most common form of the carotenes is the beta carotene which can be found in oranges, yellow, and green leafy fruits and vegetables. They can be sourced from vegetables and fruits like broccoli, carrots, lettuce, spinach, tomatoes, sweet potatoes, and oranges. Some other nutraceuticals that possess cancer preventive properties (Swaroopa and Srinath 2017) include beet roots, cucumber fruits, spinach leaves, and turmeric rhizomes. Others are soy foods which are source of Iso-flavones and curcumin (which is a polyphenol of turmeric) which possesses anti-carcinogenic, antioxidative, and anti-inflammatory properties.

Some nutraceuticals possess phytochemicals, such as the following:

- Flavonoids which block the enzymes that produce estrogen thereby reducing the chances of estrogen-induced cancers.
- Saponins which contains antitumor and antimutagenic activities.
- Phytoestrogens, recommended to prevent prostate/breast cancer.

Lycopene which protects against cancer and can be found as concentrates in the skin, testes, adrenal, and prostate.

(iv) Diabetes Polyphenols are unique nutraceuticals and supplementary treatments for various aspects of type 2 diabetes mellitus. Some complications of diabetes like nephropathy, retinopathy, and neuropathy can be prevented by polyphenolic compounds. The following substances have also been reported to be useful in diabetes management (Swaroopa and Srinath 2017). They include the following:

Lipoic acid, which is an antioxidant useful in the treatment of neuropathy in diabetics.
Dietary fibers from psyllium have been used for controlling the glucose level in diabetics.
Ethyl esters of n-3 fatty acids may be beneficial in diabetic patients.
Docosahexaenoic acid has been found to be useful in modulating insulin resistance.

(v) Anti-inflammatory Activities Linoleic acid have been in use for treating problems with inflammation and autoimmune diseases (Formica and Regelson 1995). This substance can be found in green vegetables, nuts, some vegetable oils, blackcurrant seed oil, cyanobacteria, and from spirulina.

(vi) Visual Disorders Some vision improving agents found in nutraceutical foods have been reported (Alarcon De La Lastra et al. 1994). These include the following:

Lutein: This is one of most important carotenoids and it is used for the treatment of visual disorders. It is found in many fruits, corn, sweet potatoes, carrots, tomatoes, and dark leafy green vegetables.
Zeaxanthin: This is used in traditional Chinese medicine mainly for the treatment of visual disorders. It is found in corn, egg yolks, and green vegetables and fruits.

(vii) Alzheimer's Disease (AD) In some disease conditions, substances like β-carotene, curcumin, lutein, lycopene, and turmeric, obtained from nutraceutical foods may exert positive effects on specific diseases by neutralizing the negative effects of oxidative stress, mitochondrial dysfunction, and various forms of neural degeneration (Glenville 2006). The various nutraceuticals, which are used to cure Alzheimer's disease are anti-oxidants like vitamin E and vitamin C, *Ginkgo biloba*, Huperzine alpha, and Huperzine serrata (Magrone et al. 2013).

(viii) Osteoarthritis The use of nutraceuticals as alternative treatment for arthritic disease is gaining recognition. Fish oils (like cod liver oil) in diet have been demonstrated in clinical trials and animal feeding experiments to highlight the efficacy of fish oils in arthritic disease. Other nutraceuticals like glucosamine (GLN) and chondroitin sulfate (CS) have been reported to be used for treatment of osteoarthritis (Kalioraa et al. 2006).

(ix) Diet-Related Diseases Some diet-related diseases like obesity, diabetes, atherosclerosis, and neurodegeneration are on the increase due to greater availability of high calorie foods as well as life style of minimal activity. Functional foods and nutraceuticals may represent a new approach to preventing or reducing diet-related diseases.

16.5 Adverse Effects of Nutraceuticals

Nutraceuticals can have some side effects on consumers for the reason that their purchase and consumption are not been regulated. Side effects could come from nutraceuticals in form of allergic reactions, insomnia, cardiac arrhythmias, interactions with other nutraceuticals and therapeutic drugs, excessive blood thinning, and other serious conditions (Anjali et al. 2018). Other adverse effects associated with the intake of dietary supplements have also been reported to include pyridoxine-associated sensory polyneuropathy in old-age patients that consume higher intake of pyridoxine (vitamin B6) (Knapik et al. 2014). There may be greater chances of occurrence of congenital irregularity in the babies which are born to ladies that consume vitamin A in high amount (Ramanathan et al. 2010).

16.6 Probiotics

Probiotics is a category of nutraceuticals which are live microorganisms, mostly of bacterial extraction but with a few fungal species, which when administered to a host in sufficient quantity confer health benefits on the host (Abatenh et al. 2018). The most extensively studied benefits of probiotics is in promoting healthy intestinal tracts and maintaining healthy immune systems. Probiotics can also be referred to as friendly, healthy, good, or beneficial microbes (Agbakoba 2018) and can be supplied through foods, beverages, and dietary supplements. Probiotics have been with humans since creation and have been used for a long time in various aspects of human's life. It has been used in fermentation of food and drinks, in aquaculture, in medicine, and recently in various aspects of biotechnology. Fermentation is a slow decomposition process of organic substances induced by microorganisms or enzymes which helps extend the shelf life of perishable foods. The earlier notion that bacteria are harmful and disease-causing agents have been negated as the various benefits of probiotic bacteria begin to emerge. It is still difficult for some people to believe that bacteria can be deliberately consumed in order to obtain healing or relief from an infection or to prevent infection from taking place. Humans have been consuming probiotics from time immemorial, and this goes to show their usefulness in promoting the healthy immune system and modulating the metabolic activities of the intestinal microbiota, thus improving the overall health of the host. In addition, they have also been involved in a lot of health benefits which may include the following:

- Lowering cholesterol levels
- Preventing bacterial infections
- Regulating hormones
- Reducing symptoms of irritable bowel syndrome (IBS)
- Relieving symptoms of thrush
- Preventing eczema in children

- Shortening the duration of diarrhea
- Preventing and treating vaginal yeast infections
- Decreasing risk of certain cancers
- Promoting vitamin and cytokine synthesis

For there to be health benefits, such a microorganism must have the ability to do the following:

- Survive the food manufacturing process
- Survive the passage through the gastrointestinal tract
- Have the ability to multiply and survive all through the ripening or storage period

The commonly used bacterial genera for probiotics are *Bifidobacteria, Lactobacilli, Propionebacteria, Bacillus, Enterococcus, Streptococcus*, and *Leuconostoc*. Probiotic bacteria must not negatively affect the quality of the product and it should be included on the Generally Recognized as Safe (GRAS) list. From fungi, there are the *Saccharomyces* species. Details of few of the probiotics include

(i) *Lactobacilli* which are found naturally in the genital tract, as well as in the urinary and digestive systems. Fermented foods like yogurt and dietary supplements also contain these bacteria. Some species of lactobacilli found in foods and supplements include *Lactobacillus acidophilus*, *L. acidophilus* DDS-1, *L. bulgaricus*, *L. rhamnosus* GG, *L. plantarium*, *L. reuteri*, *L. salivarius*, *L. casei*, *L. johnsonii*, *Lactobacillus pentosus* KCA1, and *L. gasseri*. They have been linked to the treatment and prevention of some infections like bacterial vaginosis, urinary tract infection, treating and/or preventing yeast infections, antibiotic-associated diarrhea, irritable bowel disease, *Clostridium difficile* diarrhea, fungal infections, traveler's diarrhea, treating lactose intolerance, skin disorders (fever blisters, eczema, acne, and canker sores), and prevention of respiratory infections (Abatenh et al. 2018).

(ii) *Bifidobacteria* which are found in the gut where they make up a good proportion of the healthy bacteria found in the colon. They appear in the intestinal tract within days of birth, especially in breastfed infants and are thought to be the best marker of intestinal health (Bokulich et al. 2016). Studies have shown that bifidobacteria can aid in improving blood lipids and glucose tolerance, effectively alleviate irritable bowel syndrome, and significantly improve digestive disorders. Some of the species of probiotic bifidobacteria include *Bifidobacterium bifidum*, *B. lactis*, *B. longum*, *B. breve*, *B. infantis*, *B. thermophilum*, and *B. pseudolongum*.

(iii) *Saccharomyces boulardii* is a fungus and a yeast probiotic. It is effective in treating acne, preventing and treating antibiotic-associated diarrhea and traveler's diarrhea as well as preventing the re-occurrence of *C. difficile* infection.

Others include the following:

- *Streptococcus thermophiles* which is known for the large production of lactase, an enzyme used in the prevention of lactose intolerance.

- *Enterococcus faecium* which is normally found in the intestinal tract of humans and animals.
- *Leuconostoc* which has been found very useful in food processing industries and have been in use for a long time.

Apart from the above listed, there is an endless list of microorganisms (bacteria and fungi) used as probiotics and the list continues to increase due to the increase in probiotic research and the increase of newly discovered microorganisms.

16.7 Types of Probiotic Foods

Some food types, especially fermented foods, are naturally quite rich in probiotics. Before the ease of modern refrigeration techniques, fermentation methods have been used to preserve foods. Many of African local foods, spices, and beverages consumed daily are actually excellent sources of probiotics. They include staples and spices like pap, *garri*, palm wine, *iru*, and *ogiri*. They are processed using local traditional food processes like fermentation, soaking, and straining. Probiotics come in various forms and from varying sources. Live probiotic cultures are often found in some fermented dairy products like yogurts and milk drinks. They may also come in form of fermented foods like pickled vegetables, tempeh, miso, kefir, kimchi, sauerkraut, and soy products. Probiotics can be supplied through beverages, foods, and dietary supplements. It can also be taken as tablets, capsules, and powders that contain the live bacteria in dried form (Suvarna and Boby 2005).

Some common probiotic-rich foods from Africa and beyond include

Yogurt This is made by the process of milk fermentation and is the most known source of probiotics. Fermented milk products usually contain less lactose than whole milk and are good replacement of milk for people with lactose intolerance. Today, yogurt can even be made from nondairy milk like coconut milk, almond milk, soya bean milk, or even tiger nut milk (Montemuno et al. 2021).

Kefir Kefir is produced when bacterial colonies are added into goat or cow's milk and allow it ferment to become a fermented milk beverage. The micro-organisms present in kefir turn lactose into lactic acid, resulting in the similar sour taste of yogurt, but with a more liquid consistency. Kefir has been found to be useful in the reduction of the blood glucose level in diabetes patients.

Cheese Some cheeses prepared from unpasteurized can be a source of probiotics.

Nono This is a local fermented milk which becomes a yogurt-like drink that is taken with millet paste called fura as a combination popularly known as "Fura da Nono."

Ogi/Akamu/Koko This is a fermented corn meal, made into a steamed porridge called "pap." It can also be made as a pudding called "agidi" or "eko" in the Nigerian local language and eaten with stews or soups. It is usually used to wean babies of breast milk and to introduce them to semi solid food.

Kenke or Dorkunu This is made from fermented white corn. It is usually eaten with proteins like fried fish, meat, and with peppery sauces.

Lafun Lafun is made from fermented cassava roots. It is meal prepared with a thick consistency and eaten with soups.

Garri Garri is cassava flour made from soaked, fermented, mashed, and dry-fried cassava roots. It can be used to make snacks like Kokoro, mixed in water and drank in form of a cereal with groundnuts and sugar or with dried fish. It can be eaten sprinkled over beans; eaten with bean ball (akara) or bean cake (moi-moi). Most popular is the stable food (eba) that is prepared by mixing the garri in boiled water to form a dough and eaten with soups.

Fufu or Akpu This is a fermented cassava paste made by fermenting the cassava root for some days and sieving to obtain a fine paste. It is prepared as a meal by cooking to obtain a stiff dough which is eaten with soups.

Masa This is a rice cake also called "Waina." It is made from short grain rice that has been soaked for hours to soften and then blended with yeast.

Ugba Also called "ukpaka" in some dialects, is made from sliced and extensively fermented oil bean seeds. It is used as an ingredient in making a meal of dried cassava flakes (Abacha). It could also be made into a local salad which is spicy and is eaten on its own.

Iru It is made from fermented African locust beans, and it is used as a condiment to spice soups. It is well known for its "phunky" smell.

Ogiri Okpei This is a food flavoring produced from fermented oil seed like egusi (melon) seeds. It has a very strong aromatic smell and is used to season several types of local dishes like soups, stews, and yam porridge.

Ogiri Igbo This is a flavoring made of fermented oil seeds, such as sesame seeds or egusi seeds. It smells like cheese, miso, or stinking tofu. It is used to season local soups and is very popular among the Igbos in Nigeria.

Palm Wine This is a sweet tasty sap obtained from palm trees.

Burukutu Burukutu is an alcohol drink made from the grains of guinea corn. The guinea corn grains undergo various processes such as steeping, malting, mashing, fermentation, and maturation before it is ready to be served as a drink.

Tempeh This is a common meat-substitute made from soybeans that have been cooked and fermented. Tempeh has a chewy texture, a nutty flavor, and has a rich nutrient content. It is rich in minerals like potassium, iron, and magnesium and contains all nine essential amino acids, making it a complete vegetable protein source.

Kimchi This popular fermented food in Korea known for its pungent aroma, spiciness, and for being rich in probiotics.

Sauerkraut This is made by fermenting cabbage.

Pickles This involves soaking of fruits like cucumbers, carrots, corn, and even apples in saltwater brine where they are turned into pickles.

16.8 The Benefits of Probiotics to Human Health

Probiotics like *Bacteroides*, *Bifidobacterium*, *Lactobacillus*, and *Escherichia coli* can be acquired by neonates from their mothers during vaginal delivery, and these beneficial bacteria are not transmitted when a baby is born by Cesarean section (Bokulich et al. 2016). This has been shown to be the reason why some infants born by Cesarean section develop allergies, have lower level of gut microbiota, and less than optimal immune systems.

Although probiotics have been in existence for so long, they have not been put into much use for treatment of infections until some years back. This is because infections were and are still been treated with antimicrobial agents. With time, microorganisms began developing resistance to some of these antimicrobials. Apart from bacteria developing resistance against antibiotics, the antibiotics cause a lot of disturbances on the microbiota of humans thus leading to dysbiosis (change in microbiota) which are capable of tilting the balance of microbes in favor of harmful bacteria thus leading to disease conditions like antibiotic-associated colitis, infectious diarrhea, vaginal and skin infections, *Helicobacter pylori* and *Clostridium difficile* infections, autoimmune disorders, and a host of others. This is where the action of probiotics come in, where good bacteria (probiotics) could be used to replace the harmful ones and restore the host microbiota to normalcy and health (Abatenh et al. 2018).

The other way that probiotics help is the impact that they have on the immune system. The immune system protects the body against harmful microbes. If it does not function properly, humans can suffer from allergic reactions, autoimmune disorders (e.g., ulcerative colitis, Crohn's disease, and rheumatoid arthritis), and infections (e.g., infectious diarrhea, *H*. pylori, skin infections, and vaginal infections). By maintaining the correct balance from birth, this will hopefully prevent these ailments.

Researches have linked probiotics to supporting the health of the reproductive tract, oral cavity, lungs, skin and gut–brain axis, and the prevention and treatment of obesity and diabetes. Currently, probiotics have been used as complementary treatment or improvement of some gastrointestinal disorders, metabolic syndromes, oral health, skin infections, and vaginal infections (Anukam et al. 2020, Onwuliri et al. 2021).

16.9 Effect of Probiotics in Some Disease Conditions

The human body normally has a microbiota which comprises both the good or beneficial bacteria and bad or harmful bacteria. It is important to maintain the correct balance between these bacteria for optimal health. Factors like age, diet, and genetics may influence the composition of the body microbiota. Dysbiosis or imbalance in the body microbiota is linked to diseases of the intestinal tract, including ulcerative colitis, irritable bowel syndrome, celiac disease, and Crohn's disease, as well as some systemic diseases like obesity and type 1 and type 2 diabetes. It can also lead to genital tract and skin infections. Some cases where probiotics have been effectively used for treatment of infections include.

16.9.1 Skin Infections

The skin as the largest organ in the body is constantly exposed to like physical, chemical, and microbial challenges. It is the first line of defense against harmful microorganisms. The skin also acts as the route through which the body expels toxins and waste. It is colonized by its own collection of microbes called the skin microbiome. The factors that determine the skin microbiome composition vary from one individual to another and are based on factors, such as age, gender, and environment. Bacteria commonly found on the skin are Brevibacterium, Corynebacteria, Staphylococci, Propionibacterium, and Micrococci (Grice and Segre 2011). Skin colonization with *Propionibacterium acnes* is associated with acne, and this can lead to an inflammatory reaction. Antibiotics are used for treating acne vulgaris but with the rise in antibiotics resistant strains of *Propionibacterium acnes* this has not been encouraging (Dreno et al. 2014). Apart from this fact, antibiotics may also cause unpleasant side effects.

Some roles that probiotics play on the skin include the following:

- Bacteria like *Staphylococcus epidermidis* and *Streptococcus salivarius are natural skin inhabitant and have the ability to inhibit* the growth of *Propionibacterium acne* (Goodarzi et al. 2020).
- Probiotics are capable of reinforcing the lining of the gut wall and inhibit the growth of pathogens that damage the delicate gut lining.
- Stress is an important trigger of acne, and probiotics can help to manage the effects of stress.
- Stress can also trigger acne indirectly by causing dysbiosis in the gut microbiome, which in turn increases intestinal permeability leading to inflammation.

Probiotics can also help in minimizing the malodor in the armpit of humans as shown in a Nigerian study. Lactobacilli were found to be part of the normal axillary (armpit) microbial community (Agbakoba et al. 2020). With that, it became necessary to explore what possible role such beneficial microorganisms will play in the axillary microbiota and odor. A body cream formulated with a probiotic—*Lactobacilli pentosus* KCA1—was applied by a selected group of young Nigerian adults to the armpit for a period of 14 days. Two swabs were collected from each of them—one before the application of the skin cream and the other at the end of 14 days of cream application. These were subjected to metagenomics analysis. The increased abundance of Lactobacilli species after the topical cream application revealed the roles; they play in keeping the axilla healthier and so may also keep the odor less malodorous. The effect of probiotics on axillary skin odor and its microbiome population therefore opens the possibility of developing new solutions for odor (Onwuliri et al. 2021).

A similar study was carried out in Belgium by Lebeer et al. (2018). Here they reported that selected laboratory strains of Lactobacilli in a viable form were used to formulate a water in oil cream. Patients with mild-to-moderate acne applied this cream facially and a reduction of inflammatory lesions was obtained. They also observed a reduction of the relative abundance of Staphylococci and an increase in Lactobacilli and concluded that microbiome modulation by addition of carefully formulated lactobacilli seems to be a new therapeutic option to reduce antibiotic use for common acne symptoms.

In another study on atopic dermatitis, 62 pregnant women with family history of Atopic dermatitis were randomized with a group receiving *Lactobacilli rhamnosus* GG (LGG) while the other group received a placebo during the last weeks of their pregnancy and continued into breastfeeding period. The research showed that infants of mothers who received LGG presented a significantly lower risk of developing this condition during the first 2 years of life (Rautava et al. 2002). Another study was carried out on 27 infants who were between 4 and 6 months and diagnosed with eczema. Some received infant formula with probiotics (LGG or *B. lactis*) and others got the same formula but without probiotics. Results after 2 months showed that the symptoms of eczema were significantly reduced in the probiotics group compared to the group that did not receive probiotics (Isolauri et al. 2000).

16.9.2 Vaginal Infections

The vagina is characteristically colonized by a protective microbiota made up of predominantly Lactobacilli species. Thus, a lack of *lactobacilli* and an overgrowth of some other microbe can cause an imbalance in the vagina. This imbalance can be due to reasons such as when a woman:

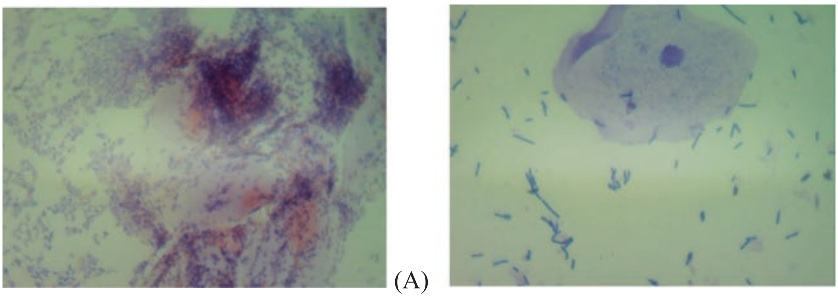
- Has unprotected sex with a male partner
- Experiences changes in hormones
- Is having her period
- Does not maintain good hygiene habits

Vaginal imbalances can result in vaginal infections like bacterial vaginosis (BV), yeast infections, and trichomoniasis.

Bacterial vaginosis (BV) is a diseased condition of the vagina whereby the normal vaginal microbiota (predominantly composed of Lactobacilli) is depleted and replaced with harmful bacteria. This leads to an increase in the normal acidic pH of below 4.5 to a pH above 4.5 thereby favoring the growth of pathogenic bacteria. With an elevated vaginal pH, women with BV often experience symptoms that include the following:

- A fishy odor
- Burning during urination
- A thin milky or gray vaginal discharge
- Itching

Microscopic examination of the vaginal swab in BV patients reveals a background of complete lack of lactobacilli as well as numerous "clue cells"—which are epithelial cells covered with Gram variable coccobacilli (Fig. 16.1a). After treating with the probiotic, *Lactobacillus pentosus* KCA1, there was a complete eradication of the clue cells and the vaginal smear returned to its normal state with numerous Gram positive bacilli (Fig. 16.1b) (Agbakoba 2018).



(A) (B)

Fig. 16.1 Gram-stained vaginal smear with (**a**) showing a typical bacterial vaginosis case with the presence of clue cells and absence of Lactobacilli (**b**) is a healthy vaginal smear showing a clear epithelial cell with gram positive bacilli (Lactobacilli) (Agbakoba 2018)

When bacterial vaginosis (BV) is treated with recommended antibiotics, there is often reports of recurrence and treatment failure. For this reason, the idea of replacing the depleted *Lactobacilli* using probiotic strains as a treatment approach was conceived (Ejike et al. 2019; Anukam et al. 2020). For the fact that BV occurs when there is a decrease in the population of vaginal *Lactobacilli* and relapses are often linked to failure to restore a healthy, *Lactobacillus*-dominant vaginal flora, then it seems logical that administering *Lactobacilli* might contribute to the treatment of BV (Morris et al. 2001).

Scientific evidence has suggested that probiotics in yogurt, capsules, and vaginal suppositories may help prevent and treat imbalance in the vagina especially in cases of bacterial vaginosis (Ebenebe et al. 2021). In a Nigerian probiotics study, seven women diagnosed with BV using Nugent score of between 7 to 10 were recruited. They were asked to provide their vaginal and gut samples before and after 14 days of oral intake of 3 g (2.5×10^8 cfu/g) of *Lactobacillus pentosus* KCA1. The probiotic was incorporated into a lukewarm yogurt and taken daily for 14 days after which the two samples were collected and re-examined using the Nugent scoring technique. Two out of the seven women showed evidence of reduced BV by the presence of Lactobacilli observed from their vaginal smears after the in-take of the probiotics and with the Nugent score dropping from 8 to 4. This showed that the normal vaginal Lactobacilli are being gradually replaced thus inferring the possibility of using probiotics in the treatment of bacterial vaginosis (Anukam et al. 2020).

16.9.3 Gastrointestinal Infections

The gut microbiome has a great influence on the health of the gut. In addition to affecting gut health locally, the gut microbiome also has effects on other areas of the body. The human digestive tract needs a healthy balance between the good and bad gut bacteria, as any dysbiosis in favor of bad bacteria can lead to different types of gastrointestinal infections.

Infections of the gastrointestinal tract are a major cause of morbidity and mortality globally. Dehydration and severe diarrhea are responsible for the death of millions of people especially children under the age of 5 annually. Implicated pathogens cut across microbial groups like viruses, e.g., rotaviruses and noroviruses; bacteria, e.g., *Campylobacter jejuni*, strains of pathogenic *Escherichia coli*, toxigenic *Clostridium difficile*, and *Vibrio cholera*, as well as parasites like *Giardia lamblia*, *E. hystolytica*, and *Cryptosporidium* species. Studies have revealed some long-lasting morbidities linked with gastroenteritis in children to include lasting disabilities, such as stunted growth, impaired fitness, and poor school performance (Guerrant et al. 2002).

Acute gastroenteritis (AGE) is the change in the consistency of stools whereby the stool becomes loose or liquid and/or an increase in the frequency of stooling to more than three times in 1 day, with or without fever or vomiting. Most often, antimicrobial agents are not needed for such infections as some of them are self-limiting.

They may however have effect on the duration and symptoms of the infection. Antimicrobial agents have the problems of microbes-developing resistance against them which in itself have led to antimicrobial-associated disease like the *Clostridium difficile*-associated diarrhea (CLAD). Antibiotics like the extended spectrum group can disrupt the normal gut microbiome leading to severe overgrowth of *Clostridium difficile* and chronic recurrent colitis (Dethlefsen et al. 2008). Such cases of antimicrobial-associated diarrhea and gastrointestinal infections have led to the need for alternatives to antibiotic treatment.

Beneficial or friendly gut bacteria (probiotics) suppress the growth of harmful bacteria and strengthen the gut wall lining. A study by Hickson et al. (2007) reported a decline in diarrheal cases after 1 week use of a combination of microbial products that included *Lactobacilli casei*, *Lactobacilli bulgaricus*, and *Streptococcus thermophilus.* Probiotics supplementation can re-balance the gut microbiome by raising the levels of friendly bacteria and suppressing the growth of harmful bacteria. Thus, rather than use antibiotics to suppress bacterial populations, probiotics can be used to restore the microbial communities to a healthy state. Probiotics have been shown to effectively alleviate disease conditions, like acute gastroenteritis (AGE), irritable bowel syndrome, and improve symptoms of gastrointestinal disorders. Probiotic bacteria have also been used as treatment for colitis, *Helicobacter pylori* gastritis, and traveler's diarrhea (Reid 2000).

Fecal microbial transplant involves the transfer of liquid suspension of stool from a healthy human donor into guts of patients to restore gut microbiota (Rupnik 2015). These fecal preparations may contain dead or viable bacteria, colonic cells, and other components that have the ability to enhance the presence of beneficial bacteria while suppressing the presence of harmful bacteria. The fecal microbiota transplantation (FMT) technique has been used successfully for some metabolic disorders as well as a variety of gut abnormality like the severe relapsing *Clostridium difficile* infection (Berg et al. 2015).

16.10 Probiotics' Side Effects

Supplements are known to augment the human diet when its supply in the diet is not adequate to supply the needs of humans. In the case of probiotic supplements, these are live bacteria, and so should be adequately stored and monitored so as to get the maximum health benefits that would be obtained from taking them. Currently, probiotic supplements are not monitored the way that food or medication is done in many countries. The onus now falls on the manufacturer of the probiotic supplement to ensure that a dietary supplement, ingredient, or product is safe before being marketed.

Probiotics' side effects, if they occur, tend to be mild and include digestive symptoms like gas or bloating, constipation, flatulence, hiccups, nausea, infection, and rash (Islam 2016). However, some people may present more serious effects. Probiotics, as live microorganisms, might at times cause infections that need to be treated with antibiotics. Such can happen mostly in people with underlying health conditions. They could also cause unhealthy metabolic activities with too much stimulation of the immune system or gene transfer.

Due to the fact that probiotics are life organisms, taking probiotic supplements may cause adverse effect on certain group of people. Such people include immune-compromised individuals, pregnant women, children, and elderly people. For individuals with compromised immune systems, caused by disease or treatment for a disease (such as chemotherapy in cancer patients or immuno-suppressive therapies), taking probiotics may increase their chances of becoming infected as a result of suppressed immune system. The use of probiotics for immune-compromised patients or patients with a leaky gut has resulted mostly to bloodstream infections.

16.11 Prebiotics and Synbiotics

Prebiotics are components of a diet if when taken can benefit the host by selectively changing the make-up or metabolism of the gut microbiota (Macfarlane et al. 2006). They are short-chain polysaccharides which have some chemical structures that are not digestible by humans. Fructose-based oligosaccharides are typical examples of prebiotics that either exist naturally in food or are incorporated in the food. Consumption of prebiotic generally promotes the growth of some probiotic bacteria like Lactobacillus and Bifidobacteria, thus helping in metabolism (Hord 2008).

Synbiotics is the combined synergistic effect of prebiotics and probiotics. Prebiotic comes first and aids the probiotic to have an enhanced performance beneficial to the host. In the gut, the prebiotic, which is a nondigestible carbohydrate, acts as food for the probiotics and other bacteria present. Probiotics can also be combined with prebiotics (nondigestible polysaccharides or oligosaccharides) to produce a more beneficial effect on a host. This combination also called "synbiont" can provide even more benefits than probiotics or prebiotics alone. Some of these health benefits include the following

- Improved lactose tolerance
- Neutralization of toxins
- Therapy for some gastrointestinal conditions
- Therapy or prevention of some types of cancers
- Reducing some allergies and inflammatory conditions
- Therapy for nonalcoholic fatty liver disease
- Fighting immune deficiency diseases
- Lowering the levels of blood lipids and cholesterol. (Isolauri et al. 1991; Fuller 1992; Sanders 1994)

Dietary intake of certain food products that have a prebiotic effect have been shown to raise the calcium absorption and bone mineral density, especially in adolescents and also in postmenopausal women.

Nearly all the identified prebiotics are oligosaccharides, and these are resistant to the enzymes in the human digestive tract that work on other carbohydrates. Thus, they go through the upper gastrointestinal system undigested. On getting to the lower colon, they become fermented and produce short-chain fatty acids (SCFAs), which then nourish the beneficial microbiota that inhabit there. Some natural sources from which oligosaccharides can be obtained or produced are artichoke, asparagus, barley, bamboo shoots, banana, garlic, honey, lentils, milk, onion, soybean, sugar beet, sugarcane juice, tomato, mustard, and wheat.

16.12 Conclusion

Nutraceuticals are natural and health promoting foods and microorganisms that have been receiving attention for being good for the health and well-being of humans. They are considered to be healthy sources for prevention of diseases as well as different infections. They are also said to focus mainly on preventive rather than on curative therapy. Probiotics are the microbial aspects of nutraceuticals that if taken prophylactically may confer a level of prevention from diseases on the host. Probiotics may also reduce the severity or duration of disease progression by reducing treatment period. They are responsible for promoting the stability of diverse and beneficial microbial communities that improve the health of humans and prevent disease. Continuous use of probiotic-containing microorganisms in food is encouraged so as to create a good balance of beneficial microbes in the intestinal microbiota. Nutraceuticals and probiotics help to achieve better quality of life and so people are encouraged to eat more vegetables, fruits, dietary, and probiotic supplements.

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Chapter 17
Phenotypic Characterisation of Nine Accessions of Okra (*Abelmoschus esculentus* (L.) Moench.)

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17.1 Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is a prominent vegetable crop in tropical and sub-tropical regions around the world (Tesfa and Yosef 2016). Okra is a member of the Malvaceae family, it is an annual plant mostly spread by seeds and has a 90–100 day life cycle (Thirupathi et al. 2012). The plant grows preferably in well-drained humus-rich fertile soil with pH ranging from 6 to 6.7 but tolerates a wide range of soil types and pH from 5.5 to 8.0 (Jain et al. 2012). Okra is an important vegetable crop that is grown for both human and industrial usage across the world (Elkhalifa et al. 2021). It possesses a number of qualities that distinguish it from other vegetables, such include excellent nutritional and medicinal properties, wide adaptability, ease of cultivation, year-round cultivation, good portability, export potential, and abundant yields (Thirupathi et al. 2012).

The fruit of okra is 10–30 cm long, 2–3 cm wide with ridges ranging from 7 to 9, it is a pubescent or glabrous pod with variable colour. The leaves, buds, and flowers are often consumed in West Africa (Siemonsma and Kouame 2000). The mucilaginous substance produced by the leaves and fruits produce makes most African delicacies, especially soup, slimy, and thick. It contains abundant mineral elements, oil, and protein sources which can be used as a coffee additive Liu et al. 2019), and

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also serves as a plasma replacement or blood volume expander (Benchasri 2012). Various antioxidants found in okra protect the kidney, are effective against diabetes, and combat liver inflammation. Also, okra promotes healthy skin and blood (Bakre and Jaiyeoba 2009) and contains high fibre which stabilises blood sugar by regulating the rate of sugar absorption from the intestinal tract (Ngoc et al. 2008). In addition, okra serves as a vision booster and also manages the human body's high cholesterol level (Sengkhamparn et al. 2009; Messing et al. 2014).

Fresh okra fruit contains 36 calories, 8 g carbohydrate, 2.1 g protein, 1.7 g fibre, 232.7 mg vitamin, 0.2 g fat, 175.2 mg minerals, and 88 ml of water per 100 g of edible portion. Its edible leaf per 100 g contains about 81 ml water, 56 calories, 11 g carbohydrate, and 4.4 g protein.

The lack of location-specific cultivars resistant to pests and diseases including the fruit and shoot borer and yellow vein mosaic virus disease has been linked to lower okra output and yield (Reddy et al. 2012). Since genetic diversity is a key factor for crop improvement, the diversity among okra germplasm played a significant role in the breeding programmes as it helps in developing varieties with desired traits (Prakash et al. 2011; Thirupathi et al. 2012). There exists a large diversity in the degree of phenotypic variation among accessions of okra especially in West African type (Tesfa and Yosef 2016) and a further collection of germplasm from the unexplored geographical areas of the country as well broadens the genetic base for the future breeding programme (Mihretu et al. 2014). Crop characterisation and assessment are done to offer information on crop diversity and to allow curators of gene banks and plant breeders to identify unique entries (accession) (Tesfa and Yosef 2016). Information on the characterisation of this important vegetable is either not accessible or simply unavailable (Osawaru et al. 2014). Hence, morphological characterisation is therefore a highly required primary step to be employed in any diversity studies prior to more in-depth biochemical or molecular studies (Tesfa and Yosef 2016). Therefore, this study was aimed at assessing the phenotypic variability of nine accessions obtained from okra germplasm.

17.2 Materials and Methods

Experimental Site The experiment was conducted at the experimental plot (Latitude: 7.214952: Longitude: 3.437090) of the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.

Sources of Plant Materials Nine accessions of okra (NGB00350, NGB00303, NGB00396, NGB00322, NGB00356, NGB00326, NGB00345, NGB00463, and NGB00335) were obtained from the National Center for Genetic Resources and Biotechnology (NACGRAB), Oyo State, Nigeria.

Experimental Design and Agronomic Practices The investigation was conducted between October and December 2017 and repeated between January and March

2018. In the open field experiment, a total of 27 bags containing 4 kg soil each were arranged at 2 m by 3 m apart in a complete randomised design (CRD) at three replications. Seeds of each okra accession were initially soaked in sterile water for 24 h. Three seeds were planted in each of the bags and later thinned to one after sprouting. Agronomic practices including watering, hand weeding, and careful tending of the plants until maturity were carried out during the period of the experiment.

Assessment of Resistance to Insect Infestation Observation was recorded on insect infestations across the replicates in each accession. Based on the percent infestations described by Mishra et al. (1988) and referenced by Gangopadhyay et al. (2017), all the accessions were classified as resistant (20%), moderately resistant (20–40%), moderately susceptible (40–60%), susceptible (60–80%), and highly susceptible (80%) (2016).

Data Collection Data collection was carried out weekly, starting from the second week after planting. Data on the quantitative characters included the number of leaves, plant height (cm), stem height (cm), and the width of leaves (cm) while the qualitative characters were leaf colour, leaf blade colour, and colour between veins and stem colour, carried out by visual observation.

Statistical Analysis The data were subjected to an analysis of variance (ANOVA), and the sample means were separated using the Duncan Multiple Test (DMRT) at a 5% probability level using SAS 9.1. (Version 2003). Simple correlation was also carried out to establish the relationship among the phenotypic characters.

17.3 Results

The results from Table 17.1 show that both accession and stages of development had a highly significant effect on plant height, the width of leaves, leaf length, number of leaves, and fruit length. Both accessions and weeks do not produce a significant effect on stem height, while the effect of the accessions was not significant for the number of fruits per plant and fruit diameter.

The result from Table 17.2 shows that the mean for accession is highly significant ($p < 0.01$) for leaf colour, leaf blade colour, colour between veins, and stem colour but not significant for fruit colour, days of sowing to emergence, and days of sowing to flowering. Also, the weeks of observation had a highly significant effect on fruit colour, resistance to insects, days of sowing to emergence, and days of sowing to flowering.

The accessions NGB00303, NGB00350, NGB00326, NGB00335, NGB00345, NGB00396, NGB00356, and NGB00463 are significantly higher ($p < 0.05$) for days of sowing to emergence, stem height, the width of leaves, and leaf length. In addition, NGB00335 showed significantly higher performance in plant height and number of leaves (Table 17.3). This was exhibited by NGB00335 on the field (Plate 17.1).

The result in Table 17.4 shows that accession NGB00322 is significantly ($p < 0.05$) lower for days of sowing to flowering, number of fruit per plant, fruit length, and fruit diameter compared to other accessions, while the number of fruit per plant is significantly higher in NGB00463 (Plate 17.2). Also, fruit diameter in the accessions NGB00335, NGB00345, NGB00356, NGB00396, NGB00463 are higher but not significantly different from one another (Plate 17.3).

The result from Table 17.5 shows that leaf colour, leaf blade colour, and fruit colour are green, while colour between veins is light green for the accessions NGB00326, NGB00335, NGB00345, NGB00396, NGB00356, NGB00463, and NGB00322 but green for NGB00303 and NGB00350. Stem colour had light green for the accessions NGB00303, NGB00350, NGB00335, NGB00345, NGB00396, NGB00356, NGB00463, and NGB00322 but light purple for NGB00326 (Plate 17.4).

The result from Fig. 17.1 shows that NGB00322 and NGB00335 are highly resistance to pest infestation, while the resistance of NGB00326, NGB00463, NGB00350, NGB00356, and NGB00396 are not different significantly ($p < 0.05$) from one another.

The result from Table 17.6 shows Prin 1 with an eigenvalue of 6.14 as the highest contributor (38%) to the total variations with significant impact on the leaf colour, leaf blade colour, colour between veins, leaf length, and leaf width. Prin 5 was the least with a 5% proportion and 0.85 eigenvalues 0.85.

Days of sowing to emergence had a strong positive significant correlation with days of sowing to flowering ($r = 0.98$). Plant height was positive and significant ($p < 0.01$) related with leaf width ($r = 0.74$), leaf length ($r = 0.76$), leaf colour ($r = 0.65$), leaf blade colour ($r = 0.65$), colour between veins ($r = 0.62$), and duration of the experiment (week) ($r = 0.67$) and showed association with number of leaf ($r = 0.54$) at $p < 0.05$. Leaf width also recorded positive and significant ($p < 0.01$) correlation with leaf length ($r = 0.94$), number of leaves ($r = 0.62$), leaf colour

Table 17.1 Mean square variation of the quantitative traits of okra accessions

Source of variation	df	Plant height (cm)	Stem height (cm)	Leaf width (cm)	Leaf length (cm)	Number of leaves	Number of fruit per plant	Fruit length (cm)	Fruit diameter (cm)
Model	17	801.23	8061.28	50.17	30.84	18.18	1.41	21.19	38.53
Accession	8	561.58**	6233.60^{ns}	39.65**	33.09**	31.31**	0.04^{ns}	1.19**	1.29^{ns}
Week	7	1275.82**	9896.82^{ns}	74.96**	35.04**	7.40**	3.38**	50.07**	92.04**
Replicates	2	98.75^{ns}	8947.41^{ns}	5.47^{ns}	7.14**	3.35^{ns}	0.00^{ns}	0.12^{ns}	0.21^{ns}
Error	198	30.83	9119.72	2.77	1.63	1.8	0.02	0.47	0.57
Corrected total	215								

ns non-significant, *df* degree of freedom
* = Significant at $p < 0.05$, ** = highly significant at $p < 0.01$

Table 17.2 Mean square variance of qualitative traits of okra accessions

Source of variation	df	Leaf colour	Leaf-blade colour	Colour between veins	Stem colour	Fruit colour	Resistance to insects	Days of sowing to emergence	Days of sowing to flowering
Model	17	0.59	0.59	2.27	6.59	1.2	7.83	20.89	3133.58
Accessions	8	1.19**	1.19**	4.74**	14.00**	0.02	0.46*	0.49	49.27
Weeks	7	0.00	0.00	0.00	0.00	2.89**	18.83**	50.07**	7549.67**
Replicates	2	0.30**	0.30**	0.30	0.30	0.00	0.39	0.31	14.53
Error	198	0.02	0.02	0.13	0.13	0.01	0.23	0.23	23.17
Corrected total	215	2							

df degree of freedom
* = Significant at $p < 0.05$, ** = highly significant at $p < 0.01$

Table 17.3 Mean performance of growth and emergence characters in okra accessions

Accession name	Stem colour	Days of sowing to emergence	Plant height (cm)	Stem height (cm)	Leaf width (cm)	Leaf length (cm)	Number of leaves
NGB00303	2.00^{b}	0.58^{a}	18.04^{cb}	15.48^{a}	6.12^{a}	5.49^{a}	4.20^{c}
NGB00350	2.00^{b}	0.63^{a}	13.33^{d}	11.56^{a}	6.05^{a}	5.20^{ab}	4.29^{c}
NGB00326	3.67^{a}	0.42^{ab}	15.48^{cd}	12.73^{a}	5.60^{a}	4.83^{ab}	4.13^{c}
NGB00335	2.00^{b}	0.42^{ab}	23.69^{a}	20.33^{a}	6.26^{a}	5.34^{ab}	5.50^{a}
NGB00345	2.00^{b}	0.54^{a}	19.10^{b}	16.56^{a}	5.51^{a}	4.61^{b}	5.25^{ab}
NGB00396	2.00^{b}	0.63^{a}	17.65^{cb}	15.06^{a}	6.00^{a}	5.47^{a}	3.83^{c}
NGB00356	1.67^{c}	0.46^{ab}	18.16^{cb}	14.72^{a}	5.43^{a}	5.19^{ab}	4.50^{bc}
NGB00463	2.00^{b}	0.50^{a}	16.12^{cbd}	13.62^{a}	5.46^{a}	4.68^{ab}	4.54^{bc}
NGB00322	0.67^{d}	0.17^{b}	5.96^{e}	62.77^{a}	2.07^{b}	1.72^{c}	1.50^{d}

Means with different letters across the column are significantly ($p \geq 0.05$) different

(r = 0.74), leaf blade colour (r = 0.74), and colour between veins (r = 0.67), while relationship with stem colour (r = 0.57) and week (r = 0.59) were significant at $p < 0.05$.

Leaf length had strong positive significant correlation with number of leaves (r = 0.61), leaf length (r = 0.79), leaf blade colour (r = 0.79), and colour between veins (r = 0.71) but was positively correlated with stem colour (r = 0.58) and week (r = 0.59) at $p < 0.05$. Similar result was obtained in the positive and significant ($p < 0.01$) association of number of leaves with leaf colour (r = 0.70), leaf blade colour (r = 0.70), and colour between veins (r = 0.67) but had significant ($p < 0.05$) correlation with stem colour (r = 0.50). Number of fruit per plant showed significant ($p < 0.01$) correlation with fruit length (r = 0.89), fruit diameter (r = 0.92), and fruit colour (r = 0.95) but related with week of observation (0.53) at $p < 0.05$. Fruit length had a strong positive significant correlation with fruit diameter (r = 0.98) and fruit colour (r = 0.89) but correlated with week (0.51) at $p < 0.05$ level of significance. Also, fruit diameter was significantly correlated with fruit colour (r = 0.94) at $p < 0.01$ and week (0.53) at $p < 0.05$. Leaf colour and leaf blade colour had a strong

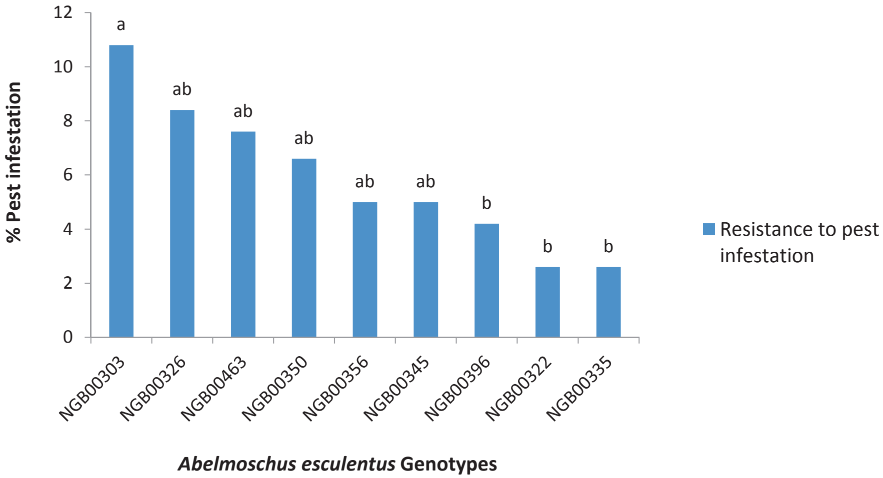

Plate 17.1 NGB00335 showing the best growth character (plant height, stem height, leaf width and number of leaves)

Table 17.4 Yield and agronomic characters in okra accessions

Accession name	Days of sowing to flowering	Number of fruit per plant	Fruit length (cm)	Fruit diameter (cm)
NGB00350	6.83^{a}	0.13^{ab}	0.27^{bc}	0.46^{ab}
NGB00326	6.79^{a}	0.13^{ab}	0.35^{abc}	0.56^{ab}
NGB00335	6.46^{a}	0.13^{ab}	0.63^{ab}	0.83^{a}
NGB00345	6.33^{a}	0.13^{ab}	0.53^{ab}	0.83^{a}
NGB00303	6.29^{a}	0.13^{ab}	0.46^{abc}	0.63^{ab}
NGB00356	6.25^{a}	0.13^{ab}	0.46^{abc}	0.69^{a}
NGB00396	6.08^{a}	0.13^{ab}	0.77^{a}	0.85^{a}
NGB00463	6.00^{a}	0.21^{a}	0.73^{a}	0.85^{a}
NGB00322	2.17^{b}	0.04^{b}	0.08^{c}	0.17^{b}

Means with different letters across the column are significantly ($p \geq 0.05$) different

positive significant correlation with colour between veins ($r = 0.94$) and stem colour ($r = 0.75$), while fruit colour showed significant ($p < 0.05$) correlation with weeks of observation ($r = 0.55$) (Table 17.7).

The dendrogram showing the relationship between the accessions of okra and quantitative characters is shown in Fig. 17.2. Accessions NGB00326 and NGB00463 are closely related but different from accession NGB00350, while accessions NGB00356, NGB00396, and NGB00303 are closely related compared to accessions NGB00345, NGB00335, and NGB00322 (Fig. 17.1).

The dendrogram showing the relationship between the okra accessions and qualitative characters is shown in Fig. 17.2. Accessions NGB00345 and NGB00396 are closely related but different from accession NGB00335, while accessions NGB00350 and NGB00463 are closely related compared to accession NGB00356.

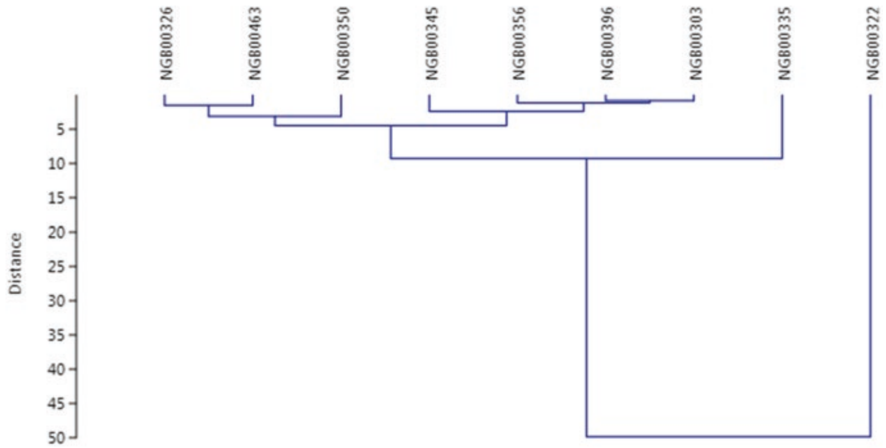

Plate 17.2 NGB00463 showing the best yield character

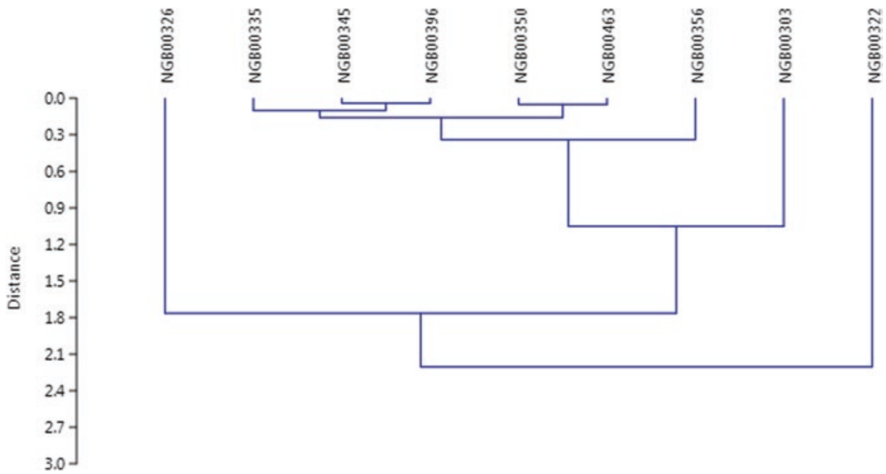

Plate 17.3 NGB00335 showing branched type of okra plant

Also, NGB00303 and NGB00326 are closely related compared to accession NGB00322 (Fig. 17.3).

17.4 Discussion

Variations in the quantitative and qualitative characters across the okra accessions as observed in this study had been considered as an important attribute in breeding programmes (Hazra and Basu 2000; Nwangburuka et al. 2012; Olawuyi et al. 2014).

Table 17.5 Colour characteristics of leaf, stem, and fruit

Accession name	Leaf colour	Leaf-blade colour	Colour between veins	Stem colour	Fruit colour
NGB00303	Green	Green	Green	Light green	Green
NGB00350	Green	Green	Green	Light green	Green
NGB00326	Green	Green	Light green	Light purple	Light purple
NGB00335	Green	Green	Light green	Light green	Green
NGB00345	Green	Green	Light green	Light green	Green
NGB00396	Green	Green	Light green	Light green	Green
NGB00356	Green	Green	Light green	Light green	Green
NGB00463	Green	Green	Light green	Light green	Green
NGB00322	Green	Green	Light green	Light green	Green

Plate 17.4 NGB00326 showing light purple type of okra plant

The performance of accession NGB00335 with the highest performance of growth characters affirmed the findings of IBPGR (1991) that a broad variation for most traits allows for the identification of promising accessions for okra. This was also affirmed in the wide variation in the plant height among the accessions studied by Ahiakpa et al. (2013). Furthermore, the accession NGB00463 with higher performance in yield and agronomic characters suggested that the inherent genetic diversity in plants and selections based on this character could improve the yield and productivity considerably (Ahiakpa et al. 2013; Voss-Fels et al. 2019).

In the qualitative analysis, despite that all accessions have similar colour for leaves, leaf blade, stem, and fruit, a distinguishing factor was observed in the colour between the veins as green in NGB00303 and NGB00350, while other accessions had light green. Although high diversity had been reported across the qualitative characters in okra species (Gangopadhyay et al. 2017), this result possibly indicates that members of each group are identical with common ancestry as verified in the study of Ahiakpa et al. (2017). Thus, the genetic affinity between the accessions could be due to the selection and exchange of okra between farmers from different regions and ethnic groups (Oppong-Sekyere et al. 2011).

Fig. 17.1 Percentage resistance of okra accessions to pest infestation. Mean with the same letter are not significantly $p \geq 0.05$ different

Table 17.6 Principal component axis of phenotypic characters in okra accessions

Character	Prin 1	Prin 2	Prin 3	Prin 4	Prin 5
Days of sowing to emergence	0.05	0.21	0.59	−0.05	0.12
Days of sowing to flowering	0.06	0.22	0.59	−0.05	0.12
Plant height	0.31	−0.03	−0.04	0.15	−0.39
Stem height	0.03	−0.02	−0.02	0.91	0.39
Width of leaves	0.34	−0.14	−0.03	0.12	−0.35
Leaf length	0.35	−0.11	−0.06	0.07	−0.28
Number of leaves	0.3	−0.1	−0.01	0.01	0.04
Number of fruits per plant	0.11	0.46	−0.14	0.01	0
Fruit length	0.11	0.45	−0.15	0.04	−0.08
Fruit diameter	0.11	0.47	−0.15	0.04	−0.06
Leaf colour	0.38	0.07	0.04	−0.08	0.17
Leaf-blade colour	0.38	−0.07	0.04	−0.08	0.17
Colour between veins	0.37	−0.07	0.05	−0.08	0.22
Stem colour	0.3	−0.07	0.04	−0.13	0.3
Resistance to insect	0.03	−0.01	−0.46	−0.27	0.5
Fruit colour	0.11	0.46	−0.13	0.01	−0.01
Eigenvalue	6.14	3.9	2.09	1.02	0.85
Proportion (%)	38	24	13	6	5

The results of NGB00335 and NGB00322 recorded as the most resistant to pest infestation among the okra accessions evaluated could be attributable to their geographical origins, as in line with the perception that wild species, in general, is considered to be the reservoir of genes especially for biotic and abiotic stresses. This corroborated the result in the study of Gangopadhyay et al. (2017) that reported yellow vein mosaic disease (YVMD), shoot and fruit borer, and leafhopper as the most common biotic stressors in okra. Furthermore, accessions from three wild species, *A. caillei*, *A. manihot*, and *A. moschatus*, were shown to be resistant to YVMD, while accessions from all four wild species were resistant to shoot and fruit borer and leafhopper.

The first three principal axes accounted for over 75% of the total variation among the 16 characters describing the accessions in this investigation. The observed

Table 17.7 Correlation coefficient among characters in accessions of okra

Correlation	D1	D2	PH	SH	LW	LL	NL	NFP	FL	FD	LC	LBC	CB	SC	RI	FC
Days to emergence																
Days to flowering	0.98**															
Plant height (cm)	0.03	0.04														
Shoot height (cm)	−0.04	−0.04	0.07													
Leaf width (cm)	−0.06	−0.05	0.74**	0.08												
Leaf length (cm)	−0.05	−0.04	0.76**	0.06	0.94**											
Number of leaves (cm)	0.00	0.00	0.54*	0.07	0.62**	0.61**										
Number of fruit/plant	0.23	0.24	0.12	−0.01	0.00	0.05	0.03									
Fruit length (cm)	0.22	0.22	0.21	−0.01	0.01	0.07	0.01	0.89**								
Fruit diameter (cm)	0.23	0.24	0.21	−0.01	0.00	0.05	0.03	0.92**	0.98**							
Leaf colour	0.11	0.12	0.65**	0.05	0.74**	0.79**	0.70**	0.12	0.11	0.12						
Leaf blade colour	0.11	0.12	0.65**	0.05	0.74**	0.79**	0.70**	0.12	0.11	0.12	1					
Colour between veins	0.11	0.11	0.62**	0.06	0.67**	0.71**	0.67**	0.11	0.1	0.11	0.94**	0.94**				
Stem colour	0.07	0.1	0.44	0.03	0.57*	0.58*	0.50*	0.09	0.06	0.07	0.75**	0.75**	0.74			
Resistance to insects	−0.39	−0.4	0.01	−0.04	−0.02	0.08	0.07	0.10	0.09	0.09	0.09	0.09	0.08	0.06		
Fruit colour	0.024	0.25	0.15	−0.01	0.00	0.05	0.06	0.95**	0.89**	0.94**	0.12	0.12	0.11	0.09	0.10	
Accession	0.01	0.00	0.00	0.00	0.04	0.03	0.06	0.02	0.02	0.01	0.00	0.00	0.08	−0.3	−0.10	0.00
Week	−0.54	−0.55	0.67**	0.05	0.59*	0.53*	0.26	0.53*	0.51*	0.53*	0.00	0.00	0.00	0.00	−0.40	0.55*
Replicate	−0.03	−0.02	−0.06	−0.09	−0.09	−0.13	−0.05	0.00	0.00	0.00	−0.17	−0.17	−0.1	0.00	−0.10	−0.02

D1 days of sowing to emergence, *D2* days of sowing to flowering, *PH* plant height, *SH* stem height, *LW* leaf width, *LL* leaf length, *NL* number of leaves, *NFP* number of fruit per plant, *FL* fruit length, *FD* fruit diameter, *LC* leaf colour, *LBC* leaf blade colour, *CB* colour between veins, *SC* stem colour, *RI* resistance to insect, *FC* fruit colour, *AC* accession, *WK* week, *REP* replicates
* = Significant at $p < 0.05$, ** = highly significant at $p < 0.01$

Fig. 17.2 Dendrogram showing the relationship among the quantitative characters of the accessions

Fig. 17.3 Dendrogram showing the relationship among the qualitative characters of the accessions

variabilities in the traits studied strongly indicate the possibility of selecting plants with suitable morphology when considering integration into any improvement programme towards preservation and conservation of okra diversity (Aremu et al. 2007; Nwangburuka et al. 2011). More so, the positive and strong correlation among the phenotypic characters established the relationship between the quantitative and qualitative characters as similarly observed by Olawuyi et al. (2015). This indicates that genetic make-up played a huge role in the phenotypic expression across the okra accessions. However, the distant relatedness among the various accessions has been suggested for consideration and incorporation into hybridisation programme in breeding for different consumer preferences and market demands (Ahiakpa et al. 2013).

The pattern of clustering of the four clusters in this investigation also revealed the degree of association between both qualitative and quantitative characters. This suggests relations with their geographic origin, as each of the clusters was possibly related to the eco-geographic distribution of the accessions. As in line with the investigation of Düzyaman (2005), each cluster members have their main characteristics, which also provide useful criteria for further evaluation of okra germplasm.

17.5 Conclusion and Recommendation

Accessions NGB00303, NGB00335, and NGB00463 are promising genotypes that could be selected and explored for future breeding in the improvement of okra. However, the resistant accessions, NGB00335 and NGB00322, can further be used in the introgression of biotic stress resistance through pre-breeding into cultivated okra species. These findings will further enhance proper documentation and conservation of okra germplasm.

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Chapter 18
Long-Term Restorative Farming Effects on Soil Biological Properties for Carbon Stock, Soil Quality, and Yield in a Nigerian Northern Guinea Savanna Alfisols

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18.1 Introduction

Burgeoning population and the need to meet the high food demand to achieve food security are some of the current challenges of sustainable food production in Nigeria. The Northern Guinea Savanna of Nigeria, one of the major food baskets, has a sub-humid climate. It has two distinct seasons with the wet cropping season starting from June and ends early October and the dry season begins from late October to early May. Rainfall ranges between 900 and 1300 mm annually. Mean air temperature ranges between 24 and 26 °C. The crops grown are mostly cereals such as maize, sorghum and millet and some legume crops like soybean, cowpea, and groundnut including cotton. The common agricultural practice is mostly mixed cropping. Continuous and intensive cultivation in the Northern Guinea savanna (NGS) is resulting in soil quality degradation, carbon stock and nutrient depletion, low crop yields and accelerated soil erosion (Odunze et al. 2017, 2019). Management practices that address the challenges of continuous and intensive crop land use, for the conservation and restoration of degraded soils are of great importance for sustainable crop production.

Alfisols, the predominant soils of the NGS are fragile and prone to rapid degradation under intensive and continuous cultivation, especially when soil cover is removed and the soil conventionally tilled as is the case in this agro-ecology (Osakwe 2014; Odunze et al. 2017). Therefore, in addition to restorative farming, field management practices which include pest management and increased soil biological activity may promote sustainability of cropping system under long-term

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continuous cultivation. This is because the essential materials needed to initiate soil biological activities carried out by the soil organisms are made available (Emmerling et al. 2001). Soil organisms are shown to improve nutrient availability, soil fertility, and crop productivity through decomposition of organic matter (Chapparro et al. 2012) and respond to sudden changes in soil conservation management practices, climate change, agronomic practices like fertilizer application, soil amendments, and vegetation cover (Chapparro et al. 2012; Rao 2013).

Therefore, investigations are necessary for microbial studies to evaluate effects of long-term sustainability of these restorative farming practices on soil microbial properties for carbon stock, soil quality, and maize grain yield using the various soil quality indicators necessary, including soil biological component. Specifically, therefore, this study aims to assess the following:

1. Long-term effect of restorative farming on soil microbial biomass and enzyme activities
2. Changes in carbon stock and soil quality status under long-term restorative farming
3. Long-term effect of restorative farming on maize grain and stover yields

18.2 Materials and Methods

18.2.1 Description of the Study Area, Weather, and Soil Condition

This trial was conducted at the Institute for Agriculture Research (IAR) field (11.1591° N; 7.6349° E) Samaru, Zaria, in the northern Guinea savanna of Nigeria during the 2016 wet cropping season on a plot that has been under continuous intensive cropping for 10 years. The area has an altitude of 683 m above sea level. The mean long-term annual rainfall in the area during the trial period was 1084.65 mm and fell within the months of May–October with a peak in the month of August. The average annual temperature was 26.36 °C. Soils of the experimental site were classified as Acrisol, FAO-UNESCO Legend (FAO 1998) and Typic Haplustaif, USDA Soil Taxonomy (1999). The soil has low inherent fertility, organic matter, CEC, and dominated by low activity clays (Odunze and Kureh 2009).

18.2.2 Treatments, Soil Sampling, and Analytical Procedures

Treatments

The treatment consists of (a) sole maize (nitrogen (N) at 45 and 90 kg N ha^{-1} (urea as N source)); animal manure-only (cow dung or poultry litter at 90 kg N ha^{-1}); 45 kg N ha^{-1} (animal manure) + 45 kg N ha^{-1} (urea) and control; (b) maize-legume system (45 kg N ha^{-1} (legume) + 45 kg N ha^{-1} (urea)); legume with maize only; *Centrosema pascuorum* and cowpea (*Vigna unquiculata*) intercropped with maize. Phosphorus at 10 kg P ha^{-1} and 30 kg K_2O ha^{-1} was basally applied to all systems adopting the Randomized Complete Block Design with factorial layout replicated three times. Plot size was 6 m by 6 m. The animal manure was incorporated into the furrows about 10 cm deep below the soil surface, a week before planting. Each experimental plot consisted of eight ridges with the four inner ridges used as net plots while the two outer ridges on both sides of the net plot as sampling plots. The maize seed variety Oba Super II, which is a long-duration (110–120 days), drought-tolerant, and N-efficient hybrid, was sown. At 2 weeks after planting (2 WAP), the first dose of split-applied urea one-third for plots requiring urea fertilizer treatment was given. The remaining two-third of the urea fertilizer was applied at 5 WAP. The method of application was the same as in the first application.

18.2.3 Soil Sampling and Analytical Procedures

A total of eight soil samples were taken along the diagonals of each plot, bulked, air-dried, crushed, and sieved through a 2 mm sieve and samples were thoroughly mixed to give a composite sample. Subsamples were taken for analyses of physical and chemical properties to characterize the initial and end of year properties of the soil. Soil samples were taken at depths 0–10 and 10–30 cm from the field. Core samples were collected using 5 cm by 5 cm core samplers for bulk density determination. At the end of 10 years of continuous cropping, soil samples were collected from each treatment plot at tasseling stage of maize for all soil analyses. One important aspect of this study was that it had been established in a low-lying area that became waterlogged during the rainy seasons. The yield data and soil characteristics documented in this study therefore reflect the long-term responses of poorly drained soils managed with different fertility sources over a 10-year period.

Measurement of soil chemical and physical properties

Parameters determined were as follows:

1. Soil particle size distribution by hydrometer method
2. Soil pH in water at a water: soil ratio of 2:1 using pH meter
3. Soil organic carbon by Walkely Black wet oxidation method
4. Total nitrogen by the Kjedahl digestion method
5. Available phosphorus by Bray 1 method
6. Cation exchange capacity of the soils using the 1NNH_4OAC
7. Bulk density by Anderson and Ingram method
8. Determination of carbon sequestration and soil quality improvement

$$\text{Carbon storage} = \text{SOC} \times \text{Area of study}\left(\text{plot size}\right)$$

This is the total carbon that could have been stored in the soil of this area within the depth in question while SOC is the carbon stock of that soil depth and calculated as:

$$SOC = \left(C \times D \times BD \times 10{,}000\right) / 1000\left(t\,C\,ha^{-1}\right)$$

Where C = organic carbon concentration (g kg^{-1}), BD = bulk density (Mg m^{-3}), depth = d (cm), 10,000 m^{-2} = 1 ha and 1000 kg = 1 ton.

Soil quality will be assessed using the Parr et al. (1992) equation:

$$SQ = f\left(SP, P, E, H, ER, BD, FQ, MI\right)$$

Where SQ = soil quality, SP = soil properties, P = potential productivity, E = environmental factors, H = Health (human/animal), ER = erodibility, BD = biodiversity, FQ = food quality and MI = management input. A score scale of 1–5 will be used in the assessment of parameters in the model, where 1 is the best and 5 worst condition.

Measurement of Soil Microbial Properties

For the microbial properties, the soil samples were sieved through a 4 mm sieve. The samples were thoroughly mixed to give a composite sample for each plot, and subsamples taken were placed in a nylon (polyethylene) bag and stored in a fridge at 4 °C on the same day and kept for 5 days before analysis.

Microbial biomass C (SMBC), N (SMBN), and P (SMBP) were estimated using the chloroform fumigation–extraction technique (Brookes et al. 1985; Vance et al. 1987; Okalebo et al. 2002) which allows for microbial biomass C and N to be determined in the same extract and does not require the microbial community to be in equilibrium (as in substrate induced respiration) (Schinner et al. 1995). After extraction with K_2SO_4 (extraction ratio 1:4), total extractable C and N were determined by the dichromate oxidation (Nelson and Sommers 1982) and Kjeldahl (Bremner and Mulvaney 1982) methods, respectively. But microbial biomass P extraction was carried out with Bray-1 extractant (soil: solution ratio of 1:4 w/v), and inorganic P (Pi) analyzed instead of total P. This was observed to improve the consistent of the P flush in soil and to provide the best estimate of soil microbial biomass P (Wu et al. 2000). Factors 1.46 (Brookes et al. 1985) and 2.67 (Vance et al. 1987) were used, respectively, for the conversion of total N and C to biomass N and C.

Four soil enzyme activities recognized as indicators of soil quality potential in soil microbial community measured were dehydrogenase activity (Deh); β-glucosidase activity (β-glu); acid phosphatase activity (AP); and protease activity (PR). Dehydrogenase enzyme is only found in viable cells, and the enzyme assay has been shown to give an ideal measure of the total microbial activity in the soil (Dick 1997).

Dehydrogenase activity was determined using the method described by Von Mersi and Schinner (1991) and Camina et al. (1998). A 0.35 mL portion of 1 M tris–HCl buffer (pH 7.5) was added to 0.25 g of soil sample, followed by 0.5 mL of 0.5% INT (Iodonitrotetrazolium chloride) solution, and the suspension kept at 40 °C for 1 h. Then 2.5 mL of extractant (methanol) was added and the sample mixed using a vortex mixer and then left in the dark for 10 min. After centrifuging for 10 min at 4000 rpm, absorbance of the filtrate was determined at 490 nm spectrophotometrically. The results were expressed as micro mole INTF h^{-1} g^{-1} of soil at 40 °C.

β–glucosidase and acid phosphatase activities were determined according to Garcia et al. (1993). A 2 mL of 0.1 mol/L acetate buffer (pH 6.5) and 0.5 mL of 0.115 mol/L paranitrophenyl phosphate (pNPP) were added to 0.2 g of wet soil sample and incubated at 37 °C for 90 min. The reaction was stopped by cooling at 2 °C for 15 min, and 0.5 mL of 0.5 mol/L $CaCl_2$, and 2 mL of 0.5 mol/L NaOH were then added with the appearance of a yellow color and the mixture centrifuged at 4000 rpm for 5 min. P-nitrophenol was determined spectrophotometrically at 398 nm. Controls were made in the same way, but the substrate was added before the $CaCl_2$ and Na0H. The results were expressed as micro mole PNP h^{-1} g^{-1} of soil at 37 °C for acid phosphatase while for β–glucosidase the results were expressed as micro mole PNG h^{-1} g^{-1} of soil at 37 °C.

Protease–casein activity was determined using the method described by Nannipieri et al. (1980) and Garcia et al. (1993). Two milliliter of casein denatured by heat and dissolved in 1% tris–HCl buffer (pH 8, 0.1 mol/L) was added to 0.2 g of solid sample and incubated at 51 °C for 90 min, 2 mL of tris–HCl buffer, and 1 mL of 17% trichloroacetic acid (TCA) were then added. After centrifuging for 10 min at 4000 rpm, the amino acids formed were determined by the Folin colorimetric method at 336 nm (wavelength). Results were expressed as micro mole tyrosine h^{-1} g^{-1} of soil at 51 °C. Controls were prepared by adding the buffer before incubation and the casein after incubation.

18.2.4 Statistical Analysis

Data obtained were analyzed by standard analysis of variance (ANOVA) using the general linear model procedure of SAS (SAS 2011) and treatment means of data generated were compared using Duncan's Multiple Range Test (Duncan 1955) at 5% level of significance ($p < 0.05$).

18.3 Results and Discussion

18.3.1 Physical and Chemical Characteristics of the Study Soil

Table 18.1 results of the soil texture of this savanna Alfisols at the commencement of study showed that it was silt loam (sand 470, silt 430, clay 100 g kg^{-1}). However, after 10 years of cropping, texture of the soil was sandy loam (sand 537, silt 327, clay 137 g kg^{-1}) at 0–10 cm and clay loam (sand 423, silt 287, clay 290 g kg^{-1}) at 10–30 cm depths. The slight increase in clay content could be due to the biological

Table 18.1 Physical and chemical characteristics of the soil

Parameters	Years	
	2007	2016
Sand (g/kg)	470	537
Silt (g/kg)	430	327
Clay (g/kg)	100	137
Silt:clay ratio	4.3	2.4
Texture	Silt loam	Sandy loam
pH 1:2.5 water	5.21	5.42
pH 1:2.5 $CaCl_2$	4.7	4.2
Organic carbon (g/kg)	5.37	2.71
Total nitrogen (g/kg)	0.45	0.43
C:N ratio	11.95	6.37
Organic matter (g/kg)	9.25	4.66
Available phosphorus (mg/kg)	11.4	11.55
Exchangeable bases (cmol/kg)		
Calcium	2.32	3.45
Magnesium	0.39	0.81
Potassium	0.21	0.04
Sodium	0.04	0.06
Exchangeable acidity (cmol/kg)	0.18	0.18
ECEC (cmol/kg)	3.14	4.54
Bulk density (Mg/m^3)	1.55	1.42

ECEC Effective cation exchange capacity (a summation of the cations)

activities of the soil organisms, clay migration, surface erosion by run-off or a combination of these (Odunze and Kureh 2009). The silt:clay ratio was 4.3 (2007) and 2.4 (2016) suggest a relatively young soil or a low degree of weathering of the parent material. Jimoh et al. (2016) has reported that when the silt:clay ratio is less than 0.15, an advanced weathering or senile soil could be inferred.

18.3.2 Effect of Cropping Systems on Soil Bulk Density After 10 Years of Continuous Cropping

The bulk density (BD) was moderately high (1.55 Mg m^{-3}) at the commencement of study suggesting that surface crusting could account for the high bulk density value. The slight reduction (1.42 Mg m^{-3}) (Tables 18.1 and 18.2) after 10 years of cropping indicating enhanced root growth and development and penetration into the soil due to improved soil aggregate stability, total porosity and available moisture content and structure, aeration, and water holding capacity. Thus, corroborating the findings of Ogunwole et al. (2010) and Eche (2011). Conditions under planted

C. *pascuorum* and manure (both cow dung and poultry litter) improved soil aggregates better due to increased soil organic matter level compared to sole mineral fertilizer application (Table 18.2), indicating that the incorporation of these soil amendments contributed to improved soil physical conditions. Evanylo and McGuinn (2000) observed similar trends and suggested that bulk density values of 1.55 to <1.65 Mg m^{-3} could affect root growth and development in silt loams while values of <1.40 Mg m^{-3} are ideal for optimum root growth.

18.3.3 Effect of Cropping Systems on Soil Carbon Stock After 10 Years of Continuous Cropping

Results on soil carbon stock is presented in Table 18.2. It showed that adoption of maize – *C*. *pascuorum* sequestered higher OC concentration (577.77 t C ha^{-1}) in the soil macro aggregate (though not determined) than the other treatments. This was followed by the animal manure- poultry litter–treated plot. It is important to note that higher OM concentration and higher mineralization rates are mostly associated with macro-aggregate fractions while OM associated with micro-aggregates may be better protected physically without being biochemical altered as attested by Odunze et al. (2017). It has also been shown (Rodale 2014) that fertility management systems and cover cropping have significant effects on the soil physical structure which results in changes in soil OM content and turnover. Hence, it can be inferred that the best land use systems are those that focus or consider the protection of soil organic carbon from being further depleted or eroded or the restoration of depleted carbon stocks through management practices that involve legume/cereal cropping system, such as maize/*C*. *pascuorum* or maize/cowpea 2:4 systems. The lowest amount of OC concentration sequestered was under cow dung–treated plots (Table 18.2).

18.3.4 Effect of Cropping Systems on Soil pH After 10 Years of Continuous Cropping

The soil reaction was pH 5.2 but increased to pH 5.4 after 10 years (Tables 18.1 and 18.3). The higher pH values obtained in the plots treated with cow dung showed that the cow dung better remediated the negative effects of mineral fertilizers better than poultry litter. This is because of the N excreted as solid urea by poultry as a result of the presence of some amino acids like methionine and cysteine added to poultry feed. This results in the release of ammonium-N (NH_4^+–N) into the soil during decomposition process. The ammonium-N (NH_4^+–N) released would further lower the soil pH, increase soil acidity, lower microbial activity (Odunze et al. 2017, 2019), leading to decreased decomposition rate as most microbes especially bacteria strive better within pH range of 7–8. It can be speculated as one of the contributing factors to the relatively lower grain yields obtained in this study.

Table 18.2 Effect of cropping systems on organic carbon, soil bulk density, and carbon stock after 10 years of continuous cropping

Treatments	OC	OM	BD	SOC
Cover crop (CP)				
No cover	1.57c	2.71c	1.49b	300.08c
Cowpea	2.23b	3.85b	1.50a	465.27b
Pascuorum	3.08a	5.32a	1.48c	577.77a
LOS	***	***	***	***
SE±	0.019	0.033	0.005	6.867
Mineral fertilizer (MF)				
Control	1.57c	2.70c	1.54b	314.03c
PK	2.13b	3.68b	1.47d	398.22b
N1PK	2.38a	4.10a	1.48c	463.49a
N2PK	1.25d	2.16d	1.59a	279.10d
LOS	***	***	***	***
SE±	0.019	0.033	0.005	6.867
Organic manure (OG)				
No organic	1.89e	3.25e	1.541a	380.168d
Poultry one	2.50b	4.31b	11.375c	443.10b
Poultry two	2.79a	4.80a	1.375c	484.68a
Cow dung one	2.30c	3.97c	1.370d	417.25c
Cow dung two	2.08d	3.59d	1.385b	382.93d
LOS	***	***	***	***
SE±	0.019	0.033	0.005	6.867
Interaction	***	***	***	***
CP × MF	***	***	***	***
CP × OG	***	***	***	***
MF × OG	***	***	***	***
CP × MF × OG	***	***	***	***
SE±	0.019	0.033	0.005	6.867

Means with same letters are not significantly different at ($p < 0.05$) using DMRT.OC (g/kg) = organic carbon; OM (g/kg) = organic matter; BD (Mg m^{-3}) = bulk density; SOC (t C ha^{-1}) = carbon stock

18.3.5 Effect of Cropping Systems on Soil Organic Carbon (OC), Total Nitrogen (TN), and Available Phosphorus (Avail.P) After 10 Years of Continuous Cropping

There was a high reduction in OC (5.37–2.71 g kg^{-1}) and OM (9.25–4.66 g kg^{-1}) (Table 18.1). This is typical of savanna soils of Nigeria and has been attributed largely to the rapid mineralization rate under high temperature, immobilization by soil microbes, runoffs, and erosion due to heavy rainfall in our environment (Shobayo et al. 2019). The C: N ratio (Tables 18.1 and 18.3) also reduced indicating high rate of mineralization due to high temperature and uptake by both plants and microorganisms. The higher organic carbon value (3.08 g kg^{-1}) obtained with

Table 18.3 Effect of cropping systems on soil pH, organic carbon, total nitrogen, available phosphorus, C:N ratio and C:P ratio after 10 years of continuous cropping

Treatments	pH water	$pHCaCl_2$	OC (g/kg)	TN (g/kg)	C:N ratio	Avail P (mg/kg)	C:P ratio
Covercrop (CP)							
No cover	5.27	4.21a	1.57c	0.52	4.57c	8.02b	285.92b
Cowpea	5.25	4.13c	2.53b	0.3	10.27a	7.19c	364.15a
Pascourum	5.32	4.18b	3.25a	0.48	6.84b	9.25a	339.45a
LOS	NS	***	***	NS	***	***	***
SE±	0.056	0.041	0.021	0.513	0.554	0.260	27.363
Mineral fertilizer (MF)							
Control	5.20b	4.20c	0.30d	0.08	4.95b	0.88c	364.58a
PK	5.34a	4.27b	2.13b	0.35	7.23a	8.99a	305.88b
N1PK	5.20b	4.09d	2.38a	0.69	5.28b	9.30a	298.38b
N2PK	5.35a	4.30a	1.25c	0.4	3.29c	4.75b	308.68b
LOS	***	***	***	NS	***	***	**
SE±	0.056	0.007	0.021	0.513	0.554	0.26	27.363
Organic manure (OG)							
No organic	5.29c	4.18d	1.81e	0.30b	6.51a	5.61e	362.73a
Poultry one	4.97d	4.28b	2.50b	1.80a	3.97c	12.14c	222.78bc
Poultry two	4.95d	4.25c	2.79a	0.55b	5.00bc	11.31d	241.67b
Cow dung one	5.45b	3.90e	2.30c	0.45b	5.11b	13.25b	183.89cd
Cow dung two	5.61a	4.45a	2.08d	0.45b	4.66bc	15.50a	144.44d
LOS	***	***	***	*	***	***	***
SE±	0.056	0.007	0.021	0.513	0.554	0.26	27.363
Interaction							
CP × MF	**	***	***	NS	***	***	***
CP × OG		***	***	NS	***	***	***
MF × OG	***	***	***	NS	***	***	***
CP × MF × OG	**	***	***	NS	***	***	NS
SE±	0.056	0.007	0.021	0.513	0.554	0.26	27.363

Means with same letters are not significantly different at ($p < 0.05$) using DMRT. TN = Total nitrogen; OC = Organic carbon; Avail. P = Available Phosphorus; C: N = Carbon: Nitrogen ratio; C: P = Carbon: Phosphorus ratio

C. pascuorum (Table 18.3) which also reflected in carbon stock (SOC) value (577 C t ha^{-1}) could be from the quick establishment of *C. pascuorum* following the first rains producing a good biomass that is left as mulch at maize planting. This feature of the legume might be a contributory factor to the superiority of the maize—*C. pascuorum* system over the maize—cowpea in terms of nutritional contribution. This result agrees with those obtained by Rodale (2014) who observed increase in organic C using herbaceous legumes as cover crops. It also suggests that *C. pascuorum* may have provided more C as an energy source for the soil microorganisms (Goladi and Agbenin 1997; Adeboye et al. 2006). The higher SOC and grain yield in the animal manure–treated plots (Table 18.2) could be attributed to improved soil water holding capacity, nutrient availability in plants, improved soil physical properties, and fertilizer nutrients efficiency by the animal manures (Eche 2011). The total nitrogen (TN) contents were generally low (Table 18.1) and not significant except for the animal manure-treated plots (Table 18.3). *Centrosema pascuorum* gave higher TN compared to cowpea, while poultry litter gave significantly ($p < 0.05$) higher total nitrogen compared to cow dung. The higher TN content by *C. pascuorum* suggests the production of a good biomass left as mulch at maize planting. Also, below ground N mineralized from previously grown *C. pascuorum* could have contributed to the higher TN obtained under *C. pascuorum* treatment. In the case of poultry litter, N excreted as solid urea could have contributed immensely to the higher TN obtained. Available phosphorus increased after 10 years of continuous cropping (Table 18.3). There was significant increase in available P in the animal manure–treated plots compared to other treatments indicating enhanced improvement in soil quality in the animal manure–treated plots (Table 18.3) that reflected also in the low bulk density and higher grain yields obtained in these treatments. The higher available P (Table 18.3) could be due to release of sufficient amounts of organic acids during organic matter decomposition and mineralization, which would have aided in P solubility, thereby improving P nutrition for plants and soil microorganisms. This is in line with the findings of Rao (2013) who observed release of good amounts of organic acids during organic matter decomposition due to hydrolysis of organic P, resulting in the improvement of P nutrition for plants and soil microbes.

18.3.6 Effect of Cropping Systems on Effective Cation Exchange Capacity (ECEC) After 10 Years of Continuous Cropping

Effective Cation Exchange Capacity and the exchangeable bases increased after 10 years of continuous cropping (Tables 18.1 and 18.4). All the basic cations were observed to increase with depth which could be due to leaching effect. Similar observation was made by Odunze and Kureh (2009), who observed increase in exchangeable bases with depth and attributed it to leaching effect as the nutrient cations move along with the soil solution. Also, activity clays (sesquioxides and kaolinite clays) and organic colloidal fractions have been observed in the Samaru savanna soils and shown to be equally low (Shobayo et al. 2019), indicating that they are susceptible to leaching. Results obtained showed that the animal manure–treated plots significantly ($p < 0.05$) gave the highest values (Table 18.4). Among the animal manure treatments, poultry litter gave significantly ($p < 0.05$) higher values for exchangeable bases and ECEC (8.57–9.99 C mol kg^{-1}) compared to cow dung (6.95–8.45 C mol kg^{-1}) (Table 18.4). Among the legumes, soils treated with *C. pascuorum* gave significantly ($p < 0.05$) higher ECEC (6.12 C mol kg^{-1}) values

Table 18.4 Effect of cropping systems on effective cation exchange capacity (ECEC) after 10 years of continuous cropping

Treatments	Ca	Mg	K	Na	ECEC
Covercrop					
No cover	4.66a	1.19	0.08a	0.07	6.17a
Cowpea	3.60b	1.11	0.06b	0.06	5.02b
Pascuorum	4.52a	1.27	0.08a	0.06	6.12a
LOS	***	NS	*	NS	**
SE±	0.479	0.132	0.009	0.007	0.180
Mineral fertilizer					
No mineral	1.67c	0.53b	0.02c	0.04b	2.44c
PK	4.96a	1.27a	0.08a	0.07a	6.57a
N1PK	4.66a	1.25a	0.09a	0.07a	6.24a
N2PK	3.76b	1.13a	0.06b	0.08a	5.21b
LOS	***	**	***	***	***
SE±	0.479	0.132	0.009	0.007	0.522
Organic manure					
No organic	3.40d	1.01d	0.06c	0.060c	4.71d
Poultry one	6.62b	1.58ab	0.12ab	0.076b	8.57b
Poultry two	7.84a	1.77a	0.13a	0.080ab	9.99a
Cow dung one	5.32c	1.27c	0.11b	0.068cb	6.95c
Cow dung two	6.59b	1.47cb	0.11ab	0.092a	8.45b
LOS	***	***	***	***	***
SE±	0.479	0.132	0.009	0.007	0.522
Interaction					
CP × MF	NS	NS	NS	NS	NS
CP × OG	***	***	***	***	***
MF × OG	***	***	***	***	***
CP × MF × OG	NS	NS	NS	NS	NS
SE±	0.479	0.132	0.009	0.007	0.522

Means with same letters are not significantly different at ($p < 0.05$) using DMRT. Ca = calcium; Mg = magnesium; K = potassium; Na = sodium; units = C mol/kg

than cowpea (5.02 C mol kg^{-1}) (Table 18.4). The high ECEC values obtained (Table 18.3) in the animal manure–treated plots in combination with mineral fertilizer compared to other treatments showed that the potential of the soil to exchange cations has been enhanced, suggesting soil quality improvement more in the animal manure–treated plots. This agrees with Cunningham (2002) who reported that application of animal manure as a restorative agricultural method rebuilds the quantity and quality of the surface while at the same time restore the natural microbial community. The restoration of the microbial community results in the improvement of the soil physical, chemical, and biological properties.

18.3.7 Effect of Cropping Systems on Soil Microbial Carbon (SMBC), Nitrogen (SMBN), and Phosphorus (SMBP) After 10 Years of Continuous Cropping

Results obtained showed an overall significantly ($p < 0.5$) higher microbial biomass in the animal manure–treated plots compared to other treatments (Table 18.5). The values obtained for SMBC ranged from 61 to 260 mg kg^{-1}. The lowest value (61 mg kg^{-1}) was recorded in the control plot and was attributed to low soil organic matter (Table 18.5). The higher values obtained in the animal manure–treated plots could be due to the presence of readily degradable C and N.

in the animal manure, added to the increased root biomass and root exudates resulting from higher crop growth. This is in line with the findings of Eche et al. (2015) who reported greater microbial biomass in soils that received yearly applications of animal manure or farm yard manure (FYM) in combination with mineral fertilizer than soils given mineral fertilizer or animal manure/FYM alone. Lower values obtained with the application of mineral fertilizer alone could result from soil acidity due to decrease in soil pH. This is observed to inhibit microbial activity, leading to decreased yield efficiency (Adeboye et al. 2006). Similar finding was reported for monoculture systems (Moore et al. 2000).

Similar trend was observed for microbial biomass nitrogen (SMBN) with the lowest (1.0 mg kg^{-1}) and highest (18.54 mg kg^{-1}) values obtained from control and animal manure–treated plots, respectively (Table 18.5). Higher values of SMBN observed in both the legume and animal manure–treated plots indicating rapid release of N during decomposition from both plots including contributions from the legume root nodules.

Soil microbial biomass phosphorus values were generally low (Table 18.5) ranging from 0.20 to 6.80 mg kg^{-1} with the lowest value from the control plot. The generally low values obtained could be due to immobilization of P by soil microorganism shown from the C: P ratio (Table 18.3) resulting in rapid depletion of P in the soil. Basal application of low P level (10 kg P ha^{-1}) which is below the recommended rate of 30 kg P ha^{-1}, for adequate crop growth and development could have contributed to the high rate of immobilization of P by soil organisms thus depleting P in the soil. This is in agreement with Sharpley (2000) that continuous cropping without addition of sufficient P resulted in P depletion due to rapid mineralization rate. This would result in poor crop growth and development, leading to low yield. Higher SMBP values were obtained in the animal manure–treated plots suggesting that release of high amounts of NH_4^+–N (especially in the poultry litter) and organic acids which may have increased soil acidity lead to P solubilization and release and increased microbial activity. Similar result was obtained by Goladi and Agbenin (1997) in their work on microbial biomass C, N, and P in the savanna Alfisols under continuous cropping.

Table 18.5 Effect of cropping systems on soil microbial carbon (SMBC), nitrogen (SMBN), and phosphorus (SMBP) after 10 years of continuous cropping

Treatments	SMBC	SMBP	MBC to MBPP	SMBN	MBC to MBN
Cover crop (CP)					
No cover	183.75b	3.89a	91.83	11.36c	25.52a
Cowpea	158.00c	3.00b	54.52	14.43a	10.96b
Pascuorum	204.00a	4.02a	51.80	11.74b	17.41ab
LOS	***	*	NS	***	**
SE±	3.523	0.493	35.65	0.099	7.201
Mineral fertilizer (MF)					
No mineral	61.00d	0.20c	372.78a	1.00d	74.56a
PK	188.40b	3.97a	53.69b	12.63b	17.94b
N1PK	203.00a	4.50a	47.68b	14.18a	15.03b
N2PK	176.00c	2.60b	67.69b	8.2c	21.46b
LOS	***	***	***	***	***
SE±	3.523	0.493	35.65	0.099	7.201
Organic manure (OG)					
No organic	149.38c	2.76b	92.98	8.92d	25.64
Poultry one	260.00a	6.00a	43.33	18.54a	13.63
Poultry two	247.00b	6.40a	38.62	18.12b	13.63
Cow dung one	250.00b	6.80a	36.77	18.02b	13.87
Cow dung two	242.00b	2.76b	84.72	17.15c	14.11
LOS	***	***	NS	***	*
SE±	3.523	0.493	35.65	0.099	7.201
Interaction					
CP × MF	***	NS	NS	***	NS
CP × OG	***	***	***	***	***
MF × OG	***	***	**	***	***
CP × MF × OG	***	***	**	***	***
SE±	3.523	0.493	35.65	0.099	7.201

Means with same letters are not significantly different at ($p < 0.05$) using DMRT. Units = mg/kg

18.3.8 Effect of Cropping Systems on Soil Microbial Activity After 10 Years of Continuous Cropping

Table 18.6 presents results of soil microbial activities evaluated from four enzyme assays shown to be potential indicators of soil quality. There was a general significant ($p < 0.05$) higher level of enzyme activities in the animal manure–treated plots compared to other treatments (Table 18.6). Similar observation was made by Nakhro and Dkhar (2010) who reported lower microbial activity and biomass under arable cropping compared to pasture. Eche et al. (2015) reported lower enzyme activities under intensive continuous mono-cropping of maize. The slightly higher values obtained from animal manure–treated plots reflected in all enzymes that were determined. This could result from the direct addition of microbial enzymes from the

Table 18.6 Effect of cropping systems on soil microbial activity after 10 years of continuous cropping

Treatments	Dehydrogenase	ß-glu	AP	Protease
Cover crop (CP)				
No cover	63.30a	23.91a	33.26b	0.43
Cowpea	42.23c	23.14c	31.09c	0.19
Pascuorum	57.41b	23.64b	35.89a	0.43
LOS	***	***	***	***
SE±	0.007	0.005	0.007	0.011
Mineral fertilizer (MF)				
No mineral	12.23d	11.66d	11.67d	0.00d
PK	53.31c	24.31b	34.39b	0.29c
N1PK	70.54b	25.62a	36.42a	0.53b
N2PK	74.15a	23.54c	34.29c	0.58a
LOS	***	***	***	***
SE±	0.007	0.005	0.007	0.011
Organic manure (OG)				
No organic	44.66e	21.50e	29.22e	0.27d
Poultry one	87.89b	27.68c	39.92c	0.72ab
Poultry two	86.44c	26.87d	38.68d	0.70b
Cow dung one	89.70a	29.43a	42.51b	0.74a
Cow dung two	84.36d	28.88b	45.14	0.38c
LOS	***	***	***	***
SE±	0.007	0.005	0.007	0.011
Interaction				
CP × MF	***	***	***	***
CP × OG	***	***	***	***
MF × OG	***	***	***	***
CP × MF × OG	***	***	***	***
SE±	0.007	0.005	0.007	0.011

Means with same letters are not significantly different at ($p < 0.05$) using DMRT. Dehydrogenase (INTF g^{-1} h^{-1}); ß-glu = ß glucosidase (PNPg^{-1} h^{-1}); AP = Acid Phosphatase (PNG g^{-1} h^{-1}); Protease (μmol tyrosine g^{-1} h^{-1})

animal manures applied. This is in agreement with Cunningham (2002) who reported that restorative agriculture rebuilds the quantity and quality of top soil and also restores the native microbial population. The combination with mineral fertilizer may have influenced dehydrogenase activity without affecting the microbial population size by suppressing some metabolic activities or microbial types. Dehydrogenase activity has been observed to be mediated by bacteria and actinomycetes groups, though little contribution comes from the fungi group (Kumuar 2003).

These disparities indicate variations in N-cycle, especially in N mineralization which shows diversity in microbial community structure.

A lot of studies have shown that organic amendments increased acid phosphatase (AP) and ß-glucosidase (ß-glu) activities (Burns and Dick 2002; Eche et al. 2015).

The soil range of activity for acid phosphatase is shown to be between 0.05 and 86.3 μmol p-nitrophenol g^{-1} h^{-1} (Nannipieri et al. 2002). Results obtained from this study (Table 18.6) agreed with their findings. The plots treated with animal manure and *C. pascuorum* gave significantly ($p < 0.05$) higher AP activity compared to other treatments. This could be due to the fact that animal manure and *C. pascuorum* supplied more phosphate to the soil, giving a more balanced nutritional status. The higher value obtained with *C. pascuorum* compared to cowpea could be due to the fact that the above and below ground residues of *C. pascuorum* probably returned much more organic material and nutrients to the soil and contributed to more microbial growth, showing that the accumulation of easily decomposable residues on and below the soil surface might have stimulated more activity, resulting in higher enzyme synthesis and improved carbon input to the soil (Dick 1997; Wick et al. 1998). The slight increase with mineral fertilizer could be due to substrate enrichment with the addition of urea to soil with moderate level of native organic matter.

Similar trend was obtained for ß-glucosidase (ß-glu), and the soil range is shown to be between 0.09 and 405 μmol p-nitrophenol g^{-1} h^{-1} (Nannipieri et al. 2002). The positive effect of animal manure on ß-glucosidase activity could be related to the quality of the animal applied. The low activity values recorded was due to the low organic matter content of semiarid soils and resistance to further degradation of the more complex (humic) organic materials. Similar observation was made by Ros et al. (2003). The better maize crop growth observed in this study with animal manure shows that this treatment had a positive influence on the synthesis of this enzyme.

Table 18.6 also presents results of protease activity. The range of activity for protease in other studies is reported to range between 0.5 and 2.7 μmol tyrosine g^{-1} h^{-1} (Nannipieri et al. 2002). The result obtained from this study showed low activity of this enzyme though the animal manure–treated plot in combination with mineral fertilizer gave significantly higher protease activity compared to other treatments. Among the animal manure, poultry litter gave slightly higher activity than cow dung. This could be due to the presence of amino acids from the poultry feeds that may have released their N content during decomposition into the soil leading to more N and thus higher protease activity. In the case of the legumes, contributions from plant root exudates of *C. pascuorum* may have caused higher N substrates to be added in the soil resulting in higher protease activity. Also, decrease in protease activity compared to other enzyme activities could be due to microbial death, because most of the substrates were no longer available to sustain this enzyme activity. Studies have also shown that substrates of this enzyme are easily degraded (Ros et al. 2003), suggesting that the proteins responsible for inducing protease enzyme along with other types of dipeptides were not present in adequate amount in the soil.

18.3.9 Effect of Cropping Systems on Soil Quality After 10 Years of Continuous Cropping

Soils developed under maize intercropped with legumes after crop residue incorporation had optimal soil pH condition, highest soil OC, TN and ECEC over the other treatments, though the animal manure–treated plots had higher ECEC and calcium (Tables 18.3 and 18.4). The poultry litter–treated plots were second to Maize/*C. pascuorum* intercrop in sequestering organic carbon, suggesting that poultry litter–treated plots developed soils of higher quality (SQ1) for sustainable crop production. This could show that the best cropping systems are those that focus on protection of soil OC from further depletion and erosion or the restoration of depleted carbon stocks through management practices that involve legume/Cereal cropping systems, such as Maize/*C. pascuorum* (Anikwe 2010). Maybe, because *C. pascuorum* is a cover crop and was able to grow better and contributed high below and above ground biomass for better soil quality development than other treatments for sustainable maize crop production. Maize/*C. pascuorum* intercrop treatment sequestered highest amounts of OC but was not as good as the animal manure plots in contributing TN, OC, or reducing soil acidity. Soil quality developed under Maize/ *C.pascuorum* intercropped was therefore rated (SQ2) and the practice reduced yield of maize grains. Result obtained also showed that application of sole mineral fertilizer resulted in low ECEC (Table 18.4), Avail. P (Table 18.3), and sequestered low amounts of carbon (Table 18.2) into the soil. This suggests that this practice may not be a sustainable practice, though yield of maize grains could provide cushioning effects against crop failure. Mono-cropping of maize encouraged soil development with high bulk density (1.54 Mg m^{-3}), poor soil structure, high soil acidity and low TN (0.08 g kg^{-1}), suggesting soils with poor quality (degraded soils) conditions, though maize yield was high, probably due to the fact that urea–N is in the plant available form that aided rapid uptake by plants. Generally, animal manure–treated plots resulted in the lowest (best) bulk density value (1.37–1.38 Mg m^{-3}), contributed highest available phosphorus (11.3–15.50 mg kg^{-1}) and was good in crop growth and development than other treatments, suggesting soils of high quality for sustainable crop production.

18.3.10 Effect of Cropping Systems on Maize Grain and Stover Yields After 10 Years of Continuous Cropping

Results of maize grain and stover yields (Table 18.7) showed that sole mineral fertilizer (urea) at 90 kg N ha^{-1} (2.582 t ha^{-1}) out-yielded the other treatments, followed by poultry litter (1.841 t ha^{-1})–treated plots in terms of maize grain with (2.582 t ha^{-1} or 2582 kg ha^{-1} giving 98.7%) grain yield improvement over the control. Following this was poultry litter combined with mineral fertilizer at 45 kg N ha^{-1} giving an increase of 98.3%. This yield level was significantly higher than other treatments and was attributed to the high OC content of soils. However, in terms of sustainability of optimal grain yield, this may not be possible because continuous crop production tends to deplete the soil of nutrients. Therefore, effective and efficient ways to reduce nutrient removal and return nutrients to soil will be needed to restore and enhance crop productivity and at the same time maintain or sustain crop productivity on a long term. Mono-cropping thus depletes nutrients from the soil. The high grain yields obtained in the legume (*C. pascuorum*)-treated plots is therefore attributed to the positive impact of this legume to contributing N and carbon stock to the soil for maize crop use.

The mineral fertilizer plots produced significantly ($p < 0.05$) gave higher stover yield than the other treatments (Table 18.7) followed by the poultry litter–treated plot in combination with mineral fertilizer at 45 kg N ha^{-1}. Higher stover yields obtained suggests high amounts of stover that could improve soil conditions if incorporated, but most of the crop residues in this savanna region are harvested, fed

Table 18.7 Effect of cropping systems on maize grain and stover yields after 10 years of continuous cropping

Treatments	Grain yield (kg/ha)	Stover yield (kg/ha)
Cover crop (CP)		
No cover	1114.0b	862.5ab
Cowpea	827c	695.2b
Pascuorum	1357.0a	1073.0a
LOS	***	**
SE±	220	223.6
Mineral fertilizer (MF)		
Control	32.3d	118.3d
PK	733.1c	581.8c
N1PK	1399.9b	1002.4b
N2PK	2582.0a	2396.7a
LOS	***	***
SE±	306.41	272.52
Organic manure (OG)		
No organic	1047	898.0b
Poultry one	1841.3a	1442.7a
Poultry two	786.3c	528.7b
Cow dung one	1427.3b	729.7b
Cow dung two	848.7c	551.3b
LOS	***	**
SE±	87.97	81.11
Interaction		
CP × MF	***	***
CP × OG	***	***
MF × OG	***	***
CP × MF × OG	***	***
SE±	67.53	75.74

to animals, used for fencing or as firewood, and are not returned back to the soil. Thus, management practices that focus on protection of soil C against continuous removal and erosion contribute N and/or restore depleted carbon stock through management practices such as legume/cereal cropping system and incorporation of animal manure in combination with mineral fertilizer are advised for sustainable agricultural production in the northern Guinea savanna zone Alfisols.

18.4 Conclusion

Findings from the study showed that bulk density ranged between 1.37 and 1.59 Mg m^{-3} and was rated moderate for sustainable crop production. Generally, soils of this study area have poor inherent fertility status and quality. Mono-cropping of maize caused high grain yields but over time will decrease due to soil compaction and acidity compared to other treatments, suggesting that mono-crop maize treatment under sole mineral fertilizer would cause a decrease in the soil reaction leading to soil compaction and progressive yield decline. Thus, this is not a sustainable cropping system option for the northern Guinea savanna zone Alfisols. The *C. pascuorum*-treated plots gave significantly ($p < 0.05$) the highest OC concentration sequestered in the soil than the rest other treatments, though they did not give the highest grain yield. Animal manure also increased ECEC showing improved soil quality for sustainable crop production but sequestered lower organic carbon content (2.08–2.79 g kg^{-1}) resulting in low soil organic matter level (3.25–4.80 g kg^{-1}). There was no significant difference in carbon stock between the plots intercropped with legumes and those treated with poultry litter, though *C. pascuorum* plots sequestered higher (577.77 t C ha^{-1}) carbon stock. The animal manure–treated plots significantly stimulated growth and activity of microbial communities (1.59%, 27.12% biomass C), (35.34%, 36.07% biomass N), (35.34%, 36.07% biomass P), dehydrogenase (20.39%, 42.80%), β-glucosidase (12.90%, 17.12%), acid phosphatase (14.92%, 19.42%), and protease (12.5%, 51.56%) in the soil better than all other treatments and ameliorated soil acid conditions, enhanced total N, and available phosphorus indicating changes in field management practices. Relationship between enzyme activities and microbial biomass differed depending on treatment, indicating differences in microbial community composition. Highest grain yield of 2.582 t ha^{-1} under sole urea at 90 kg N ha^{-1} and poultry litter combined with urea at 45 kg N ha^{-1}, followed by cow dung combined with urea at 45 kg N ha^{-1} and least legume (cowpea) intercropped with maize combined with 45 kg N ha^{-1} (urea). The best soil quality (SQ1) was ascribed to combined poultry litter (45 kg urea + 45 kg poultry − N (1.5 t ha^{1}) and *C. pascuorum* intercropped and relayed. Thus, organic amendment combined with mineral fertilizer including legume intercropped is recommended for long-term restorative farming.

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Part III
Climate Change and Sustainable Food Production

Chapter 19
Impact of Climate Change on Food Security for Health Management and Its Adaptation Strategies for Sustainability among Households in South-East Nigeria

Unoma C. Onuorah

19.1 Introduction

19.1.1 Background of the Study

Climate change is a natural process and human modifications exist that can cause the climate to change. It also can be a gradual change in the atmospheric system both natural and physical. It is the accumulation of manufactured gases that traps the heat of the sun causing changes in the weather pattern. It could be the modification of an area's normal yearly precipitation—forms of water particles (e.g., rain, snow, hailstorm)—or adjustment in an area's normal temperature for a month. Climate change is a global problem triggered by natural and human activities.

Okoli and Ifeakor (2010), in Onyeazor and Chike (2020), illustrate that climate change is a global effect that is caused by natural increases in the concentration of carbon dioxide and other heat-trapping gases (e.g., methane, ozone, nitrous) that occur naturally in the troposphere (i.e., lowest layer of the earth atmosphere). The greenhouse gases prevent the direct heat of the sun from heating the surface of the earth, increasing emission of carbon dioxide into the atmosphere. This leads to the depletion of the ozone layer—a poisonous reaction (hazardous)—that increases the earth's surface temperature affecting agricultural growth.

According to Onuorah and Nwabunwanne (2013), the greenhouse effects are the human activities or development that cause carbon-based gases to block heat from escaping. Those long-lived gases are in the other permanent part of the atmosphere and force climate change without a chemical or physical reaction. Heating of the ozone layer (inhibiting the rise of the sun) thereby causes climate change to affect

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agricultural plants. The increased temperature that flows by the melting ice of the polar region causes water to travel into the rivers and oceans; sometimes this causes floods and changes in crop management and other agricultural activities.

Climate change affects farming; it changes the average temperature, rainfall, and weather extremes (e.g., heat waves), leads to pests and diseases, atmospheric carbon dioxide, and ground-level ozone concentrations. Such changes destroy the nutritional quality of most foods. For example, droughts cause food and economic losses because of disruption in plant growth, productivity of crops and livestock, fruit crops and milk yields, leading to mass food shortage and lack of food stuff for transport. According to USEPA (2015), transportation changes can reduce the ability for exportation of agricultural products of farmers to various international markets. This affects agricultural production and exportation growth as well as global food prices, thus, creating a serious impact on food security.

Food security is the measure of available food and the ability of individuals to access it. This is especially necessary and important for the total population to be food secure; the rich, the poor, male, female, young and old need adequate access to food.

According to the USDA (2015), climate change affects food security at the global, regional, and local level. It disrupts food availability and affects food quality. Climate change is because of the increase in temperature, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability, causing reduced agricultural productivity, spoilage, and contamination. It reduces the sugar content of food, increases weeds, causes bad coloration, and destroys storage stability in fruits. This can cause disease fungi (e.g., mildew, spotting on leaves, yellowing, among others), harmful insects, and reduction in land quality.

Fisheries are affected because they depend on specific climate conditions (e.g., temperatures, droughts, floods, habitat range; and crop planting dates) that shift and hinder farming practices. Thereby, this creates poor food production leading to reduced nutrition intake for health management and at times death. Globally, every individual health is being affected by climate change mostly because of poor food quantity and quality. Examples: during extreme weather change; heat, poor air quality, even extreme cold, severe floods/droughts; all these affect the quality of food production and territory (Ebele and Emodi 2016). This leads to poor food nutrient content and food scarcity that often affects individuals, especially the very young and old. Such groups (e.g., both educated and uneducated, the poor, pregnant women, and dignitaries in the community, among others) need appropriate food for health sustainability but do not benefit.

According to Alonso (2020), biological diversity is essential for human health and well-being, economic prosperity, and food safety and security. Alonso further stated that ecosystems, and ecological processes supply oxygen and clean water, they help cycle carbon and fix nutrients, enable plants to grow, keep pests and diseases in check, thereby protect against flooding and regulate the climate. Most foods are not appropriate because of loss of nutrient, and some that are appropriate are scarce, expensive, and cannot be obtained by many owing to a lack of money. Human health is greatly affected by climate change (WHO 2015), especially by nutritional deficiencies.

According to Olsen and ACSM health editorial team (2019). anemia is recognized as a public health epidemic; more than 30% of the world's population is anemic. This is because of inadequate food intake such as dark leafy greens, red meats, and egg yolks (for red blood cells). Reduced intake of anti-oxidants (beta carotene) from red, orange, and dark green produce, as well as milk, eggs, and fruits, can cause poor eyesight, inadequate functioning of reproductive health in men and women, and excessive infections as a result of a poor immune system to protect against infectious diseases. Inadequate intake of vitamin A impacts the nervous system, weight and memory loss, and nerve and muscle damage, thereby affecting the heart. When fatigue and confusion are neglected, it can lead to death.

Climate change affects the body's DNA because of a lack of agricultural food intake of folic acid (i.e., vitamin B-9) that helps brain development; spinal cord and nervous system functioning, especially fetal development; birth defects; growth problems; and/or anemia (Olsen and ACSM 2019). Agricultural food products (e.g., beans and lentils, citrus fruits, leafy green vegetables, asparagus), meats (e.g., poultry, pork), shellfish, grain products (but fortified), and whole grain are needed for consumption. Olsen and the ACSM (2019) further stated that the National Institute of Health (NIH) recommends that women who are pregnant or may become pregnant should consume up to 4000 μg of folic acid each day, over and above the Folate (vitamin B9) received from food, which naturally helps prevent birth defects and is very important. Vitamin D is also obtained from agricultural produce, fish liver oils, fatty fish, mushrooms, egg yolks, and liver; when deficient in the body, it can cause unhealthy bones.

The body needs the right amount of calcium to regulate the development of teeth and bones. A lack causes stunted or inadequate bone growth and, when combined with a lack in calcium, can lead to porous and fragile bones (osteoporosis). Climate change is very much affecting human health. Scientists have observed that climate change is occurring too fast for species to adapt and survive. Alonso (2020) noted that fungi, microbes, and animals are the source of unique and innovative molecules that form the basis of new medicines.

Biodiversity provides models with which to study health and diseases, contributing to improvement in treatment and survival rates. Climate change needs a good strategic plan to enable good health management conditions. Mercer and Bartram (2011) recognized that a plan should be implemented to make incremental improvements over time, prioritizing public health risks by addressing the greenhouse gasses accordingly. That is part of the reason why the researchers carried out the study. They observed that there is inadequate health management among various households in South-East Nigeria because of problems from climate change that affect agriculture.

This has been impacting health management of individuals in certain households. There is need to prevent health risks from inadequate agricultural food intake. That is why the study of climate change influences food security for health management and its adaptation strategies for sustainability among households in South-East Nigeria. This will enable health management sustainability of every household.

The main purpose of this study was to determine climate change's impact on foods security for adaptation strategies for sustainability among households in South-East Nigeria. Specifically, the study sought to:

1. Determine the impact of climate change on food security for health management among households in South-East Nigeria and its adaptation.
2. Determine climate change adaptation strategies for food security for health management among households in South-East Nigeria.

This study pursued answers to the following research questions:

1. What is climate change's impact on food security for health management among households in South-East Nigeria?
2. What are the climate change adaptation strategies for food security for health management among household in South-East Nigeria?

19.1.2 Design of the Study

The study used a survey design to collect relevant information. The survey design involves assessment of the people's attitudes, motivations, interests, and opinions. Survey research, according to Check and Schuit (2012), is the collection of information from a sample of individuals through their responses to questions. They further stated that this type of research allows for a variety of methods to recruit participants, collect data, and uses various methods of instrumentation.

The study was done within the capitals of the five states in South-East Nigeria comprised of Abia, Anambra, Ebonyi, Enugu, and Imo. The capital cities are Umuahia for Abia State, Awka for Anambra State, Abakaliki for Ebonyi State, Enugu for Enugu State, and Owerri for Imo State.

19.1.2.1 Population of the Study

The population was comprised of all the senior healthcare workers in all the state government-owned general hospitals within the five (5) south-eastern states as well as the agricultural extension officials from the five agricultural development programs within South-East Nigeria. This means that there was a population of 200 respondents.

19.1.2.2 Sample and Sampling Technique

A multistage sampling technique was used to select respondents for the study. Stage One involved the sampling of two (2) general hospitals from each of the five states, giving a total of ten (10) hospitals. Stage Two involved the sampling of ten (10) senior healthcare officials and ten (10) agricultural extension officers from each of the hospitals, giving a total of 200 senior healthcare workers and agricultural extension officers. This resulted in a total sample size for the study of 200.

The instrument used for data collection was a structured questionnaire. Its items were generated based on the information collected from the review of related literature. The questionnaire was made up of two sections (1–2) with thirty-seven (37) items and was coded based on a four-point rating scale: strongly agreed (SA) = 4, agreed (A) = 3, disagreed (D) = 2, strongly disagreed (SD) = 1, respectively. The researcher, with the help of research assistants in each government-owned hospital in each of the states, administered the questionnaire to all respondents.

The instrument was subjected to face validation by producing draft copies of the questionnaire. These were given to three experts in the field of science education who critically examined the items included with the specific purpose of the study in mind and made useful suggestions that improved the quality of the instrument. Their recommendations, advice, suggestions, and observations were used to review the questionnaire items. To determine the reliability of the instrument, the questionnaire items were administered to five scientists outside the southeast zone. This was done to ensure that the respondents used in the reliability testing were excluded from the study sample. Their responses were subjected to a reliability test using Cronbach's Alpha Coefficient; the result was 0.75 and was considered reliable to be used in collecting data for the study.

19.2 Method of Data Analysis

Two hundred (200) questionnaires were administered by hand to the respondents and 150 were returned with the help of research assistants. Frequency counts and means were used to analyze the data collected. Any item with a mean score of 2.50 and above was regarded as "agreed." Similarly, any item scored 2.49 and below was regarded as "disagreed."

19.3 Results

Table 19.1 shows that all the respondents accepted all the items except item 11 with mean score below 2.50 as disagree for climate change impacts on food security for health management among households in South-East Nigeria.

Table 19.2 shows that all the respondents accepted all the items except four items that were below the mean score of 2.05 and were not accepted to be appropriate for climate change potential adaptation strategies for health management among households in South-East Nigeria. Figure 19.1 identify the degree of agreement in height and width where "disagree" are shorter in height and "agreed" are with longer heights as can be seen in the graph. this, further confirms Table 19.1 to be climate change impacts on food security for health management in Southeast Nigeria. Figure 19.2 Identifies the degree of agreement and disagreement in height and width where the disagreed are shorter in height but with the same width from those of agreed as can be seen in the graph below, where the four shorter heights indicates the four items that disagreed.

Table 19.1 Mean Rating on Climate Change

S/N.	Impact on Food Security on Health Management Include:	$\bar{X}$	RMK
1.	Low food production affects health	3.27	Agreed
2.	Improve vegetable and agricultural food growth	3.36	Agreed
3.	Poor (inadequate) rain for agricultural food and nutrient content	3.45	Agreed
4.	Industrial pollution affects agriculture as well as food intake	3.34	Agreed
5.	Deteriorating water quality leads to poor crop quality	3,25	Agreed
6.	Decreased crop yield affects population food intake for health	3.31	Agreed
7.	Poor agricultural produce and nutrient content	3.30	Agreed
8.	Reduces illness due to affected food intake	3.25	Agreed
9.	Low (inadequate) quantity of food for the population	3.35	Agreed
10.	Increased diseases (e.g., salmonella, diarrhea)	3.50	Agreed
11.	Improved body system due to agricultural chemicals	2.05	Disagreed
12.	Low diet intake due to poor agricultural yield	3.37	Agreed
13.	Insufficient food nutrient intake	3.35	Agreed
14.	High cost of food for living	3.42	Agreed
15	Spreading of malnutrition due to agricultural food handlers	3.30	Agreed
16.	Threat to agriculture and food production	3.40	Agreed
17.	Limiting access to food	3.37	Agreed

Table 19.2 Mean Responses on Climate Change

S/N.	Adaptation Strategies for Health Management Include:	$\bar{X}$	RMK
1.	Establishing change in agricultural practices	3.42	Agreed
2.	Raise awareness among healthcare professionals and farmers	3.28	Agreed
3.	Improving human activities to increase climate change for agricultural	2.27	Disagreed
4.	Speak up	3.35	Agreed
5.	Weatherize (protect) for agricultural cultivation	3.29	Agreed
6.	Increasing emission of greenhouse gasses	2.18	Disagreed
7	Construction/modification of waterways for agriculture	3.32	Agreed
8.	Integrating crop livestock-forestry system	3.35	Agreed
9.	Managing climatic risk by farmers and individuals	3.42	Agreed
10.	Implement climate change hygiene and health education program	3.26	Agreed
11.	Climate change program should be avoided	2.37	Disagreed
12.	Construction and maintenance of the sea and roads for agricultural product transportation	3.52	Agreed
13.	Improving biodiversity	3.27	Agreed
14.	Use scarce water resource building method for future climate	3.33	Agreed
15	Flood / drought defense	3.26	Agreed
16.	Increase demand of fossil fuels	2.10	Disagreed
17.	Rehabilitation of pastures	3.30	Agreed
18.	Recycling household waste	3.45	Agreed
19	Addressing greenhouse gases accordingly	3.24	Agreed
20	Avoid chemical water treatment from agricultural farm	3.28	Agreed

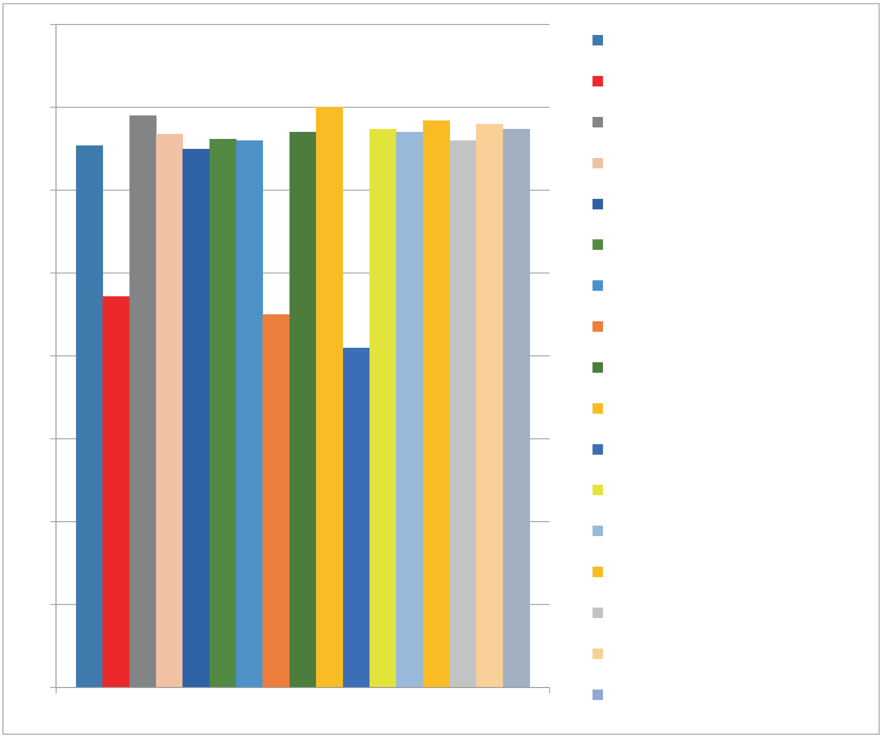

Fig. 19.1 Mean responses on climate change adaptation strategies on food security for health management in Southeast, Ni

19.4 Discussion/Conclusion

Climate changes are the gradual change in the climate structure both natural and physical. It is the accumulation of man-made gases that traps the heat of the sun causing changes in the weather pattern. The findings of this study about climate change (Potential Impacts on Food Security for Health Management) and its adaptation (Strategies for Sustainability among Households in South-East Nigeria) showed that natural processes and human activities affects climate change. This causes poor growth, reduced nutrient content, as well as low produce quality of most available agricultural plants, leading to individuals' inadequate quantity of food intake in most of South-East Nigeria and globally.

It was observed from literature that there is worldwide climate change, and this has had an impact on food security and overwhelmingly detrimental effects on health management of the world. Spillages of crude oil in the environment; leakages from pipelines, underground and surface fuel storage tanks; indiscriminate spills,

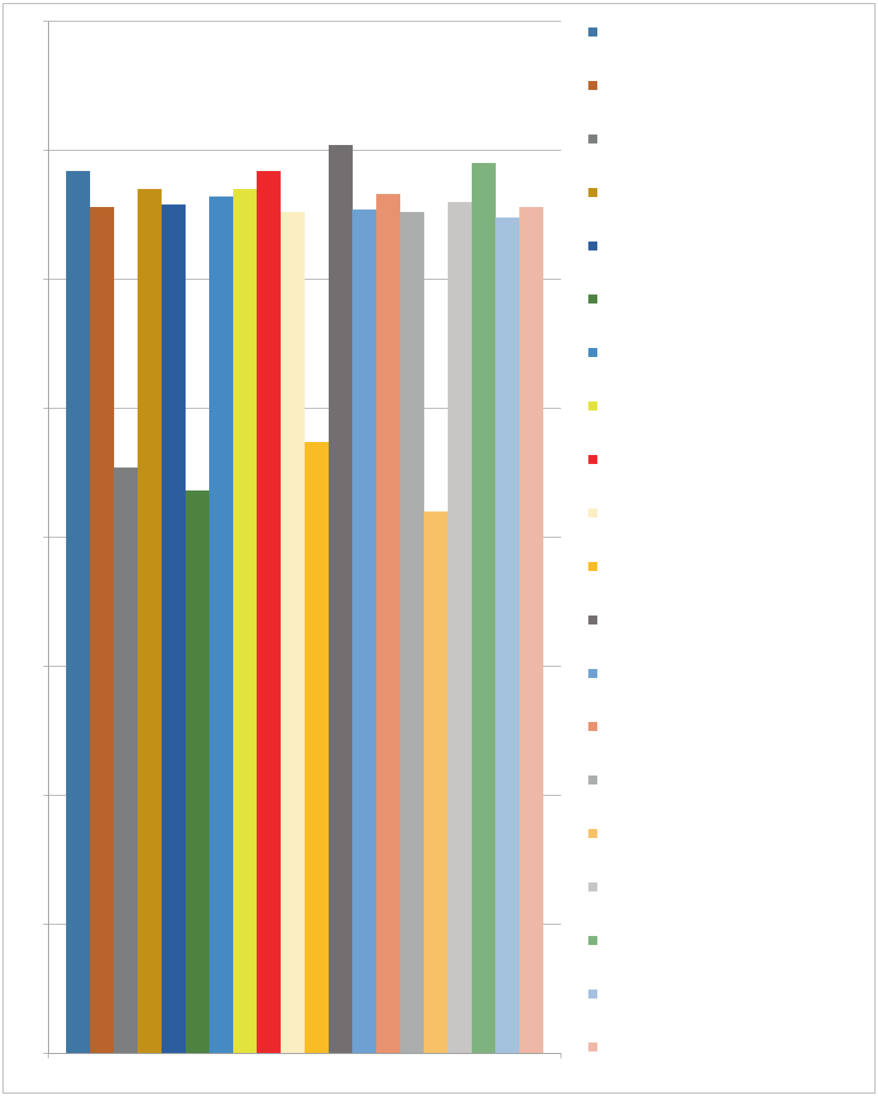

Fig. 19.2 Mean rating of responses on climate change adaptation strategies on food security for health management in Southeast, Nigeria

careless deforestation, mismanagement of waste, and improper land use constitute the major sources of human activities. Changes have been caused by releasing a large amount of carbon dioxide into the atmosphere triggering a rise in the greenhouse effect.

The preceding is the major area that needs intervention against climate change and its impact on food security for health management. This result also proves that there are potential climate change effects, thus, reduced food production and inadequate crop growth. Chemicals used on farms to protect crops can decrease fruit and vegetable growth. There may be inadequate rain for agricultural food and good nutrient content because of industrial pollution and greenhouse gases, among others. The adaptation strategies for instituting changes in food production practices include: awareness on climate change threats for agricultural products, reduced emission of greenhouse gases, chemical water treatment, sanitation, and control of hazardous materials from farms among others.

This is where the researchers anchored the study to improve health management and its adaptation strategies for sustainability among households in South-East Nigeria. Therefore, this study is important globally to control climate change and potential impacts on food security for health management among households. The study targets and corrects incorrect attitudes and other bad practices that cause climate change's impacts on food security.

Recommendations
From the findings of this study, these recommendations are being made. It is necessary for the governments to do the following:

- Develop educational knowledge, such as this study, from time to time to better understand climate change's potential impact on food security for health management.
- Develop tools and methods to intersect climate change and its impact on agriculture.
- Explore root causes of the effects of climate change on agriculture for development of qualitative and quantitative food nutrients in various institutions in the country.

Appendix: Population Sample for Distribution of the Questionnaire

S/N.	States	Capital Cities	No. of Teachers (Science Lecturers)	No. of Health Personnel
1.	Abia	Umuahia	20	20
2.	Anambra	Awka	20	20
3.	Ebonyi	Abakaliki	20	20
4.	Enugu	Enugu	20	20
5	Imo	Owerri	20	20
Total			100	100

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Chapter 20
Climate Change, Growth in Agriculture Value Added, Food Availability and Economic Growth Nexus in the Gambia: A Granger Causality and ARDL Modeling Approach

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20.1 Introduction

The Gambian economy is predominantly reliant on agriculture, tourism, and remittance. Farmers are wedged in a ring of low income with high risk related to low rainfall and high temperature.

In the last few decades, climate change has become an important topical issue in world policy agenda. It is evident that climate change affects agricultural productivity through variations in temperature and precipitation. From the mid-1960s, changes in the climate of the Gambia has been characterized by irregular rainfall patterns, storms, incidence of drought, and cold spells among others (Loum and Fogarassy 2015). This is seen to have tremendous effect on agricultural production.

In addition, it is projected that climate variability will pose both short-term and long-term hindrances to advancing crop production and livelihood of rural farmers. The cases of deleterious extreme weather events such as floods, windstorms, rainstorms, drought, and dust storms are now more frequent and present long-term

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challenges to the agricultural productivity, food security, and malnutrition (Loum and Fogarassy 2015).

According to FAO, poverty, food insecurity, and malnutrition have remained unchanged in the Gambia in the last 10 years. Food insecurity in particular has risen from 5% to 8% over the past 5 years as a result of drought, floods, and weak food production capacity (FAO et al. 2019). According to FAO (ibid), the Gambia depends heavily on food imports and produces only 50% of the food it needs. There is a strong evidence that climate change affects food availability in the Gambia.

The Gambia performs relatively badly in terms of human development as the country was ranked 174 out of 189 countries in 2017 in terms of the Human Development Index (HDI) (FAO et al. 2019). Most recent studies indicate that this low level of human development is attributable to low agricultural productivity. In a study conducted by Sillah (2013), it was found that agriculture productivity is the most important variable for economic growth in the Gambia. According to Sillah (ibid), capital per worker is a significant and relevant factor input for economic growth in the Gambia. Furthermore, agriculture labor per acre was found to be irrelevant in both short- and long-run analysis (Sillah, 2013).

In terms of the relationship between food insecurity and rural development in the Gambia, Patrick (2009) found that relatively moderate effects of various interventions, particularly in the Western and Northern Bank Divisions of the country, where agricultural production of various crops and livestock has improved the livelihood of those particular rural communities. Goshu and Yimer (2017) studied the dynamics of food security in sub-Saharan Africa. The results revealed that the food stock level of sub-Saharan African countries was improved by agricultural production and industrial value added.

Bakari et al. (2018) studied the impact of the agricultural trade on a country's GDP and showed that agricultural trade has a positive correlation with gross domestic product. However, agricultural exports and gross domestic product have a weak correlation (ibid). With the help of the static gravity model, Bakari et al. (2018) further show that agricultural exports have a positive effect on economic growth. On the other hand, agricultural imports were found to have limited effect on economic growth. These results suggest that agricultural exports are the driving force for economic growth in North African Countries (Bakari et al. 2018).

In order to have the ideas of the methods used in this study, we now present different authors' viewpoints. Chabbi's (2010) study investigated the impact of agriculture on economic growth for the Tunisian economy during the period 1961–2007, applied Johansen's multivariate approach, and found that agriculture plays a key role in determining economic growth.

Omri and Kahouli (2014) inspected the nexus between domestic investment and economic growth for 13 MENA countries for the period 1990 to 2010. By using the Generalized Method of Moments (GMM), they found that there is an optimistic bidirectional causality relationship between domestic investment and economic growth.

On the other hand, Keho (2017) used the autoregressive distributed lag (ARDL) model and Granger causality tests and found that there is a positive bidirectional causality relationship between domestic investment and economic growth in both the short and long run in the case of Cote D'Ivoire for the period 1965–2014. Adams et al. (2017) used the ARDL model and the results of the study revealed that domestic investment has a positive influence on Nigerian economic growth in the long run. Herrerias (2010) observed for the Granger causal relationship between industrial investments on economic growth in China for the period 1964–2004. He found out that industrial investment has a positive impact on economic growth in the long run. The results of the study by Herrerias (2010) showed that industrial investment impacted positively on China's long-term economic growth between 1964 and 2004. However, in the short term, there was no relationship between the two variables.

Furthermore, Tiba and Omri (2017) studied the relationship between CO_2 emissions and economic growth for the case of 24 middle- and high-income countries from 1990 to 2011 by applying panel simultaneous equations model. The results from this study showed the presence of bidirectional causality relationship between CO_2 emissions and economic growth.

Ceesay et al. (2021) studied the environmental kuznet curve (EKC) hypothesis by using empirical panel data estimation and revealed that growth for CO_2, which is used as a proxy for environmental quality or industrialization level revealed that growth for population density, growth of per capita income, growth of per capita income squared, growth of trade openness, growth of exchange rate, and growth of agriculture valued added, were statistically significant. The results further indicated that growth of trade openness leads to an increase in growth of environmental quality.

The study of Ali et al. (2019) explored the causal relationship between agricultural production, economic growth, and carbon dioxide emissions in Pakistan. An autoregressive distributed lag (ARDL) model was applied to examine the relationship between agricultural production, economic growth and carbon dioxide emissions, results provide evidence of short-run and long-run relationships between agricultural production, gross domestic product (GDP), and carbon dioxide emissions in Pakistan. In addition, by Ali et al. (2019), which investigated the correlation between carbon emissions, gross domestic product, cereal crop production, and agriculture value added using time-series data from 1961 to 2014. The result of this study shows that there exists both short-run and long-run association between agricultural production, economic growth, and carbon dioxide emissions in Pakistan.

The aim of the present study is to build on the above studies by demonstrating the nexus between climate changes, growth in agriculture value added, food production, and economic growth in the Gambia with the help of a Granger causality framework. Further aim of this chapter is to determine, using the ARDL model, whether the growth in food import and growth of agriculture have negative impacts on the growth of the Gambian economy. There is no known paper that examines this aspect of the literature, which researchers use time-series approaches for this purpose. Therefore, this chapter is timely and will help policy makers understand the important linkages between climate change and food production, on the one hand, and, on the other hand, the ways and manner in which the country's agriculture, climate change, and economic growth are connected and affecting each other due to shocks in one variables over the others. As a result, a key contribution of this chapter is that it sheds light on the various policy options at the disposal of policy makers in their quest to address the immense challenges caused by food insecurity in the Gambia.

20.2 Theoretical Model

This chapter adopts the theoretical concept of production function by including climate variables into it as used by Apergis and Payne (2011), Lee and Lee (2012), Ceesay (2020), Belford et al. (2020), which forms the theoretical basis for the study. Since growth in accounting equation offers guidance for the decomposition of climate change, agriculture value addition, food production, and their impact on economic growth as derived below:

In their framework presented as:

$$Y_{it} = F\left(\mathrm{CO2}_{it}, \mathrm{FP}_{it}, \mathrm{AVA}_{it}, \mathrm{L}_{it}, \mathrm{K}_{it}, \mathrm{Z}_{it}\right) \tag{20.1}$$

where:

Y_{it}: Economic growth/the rate of change of real GDP/GDP per capita,current U.S.dollars,at time *t* and observation *i*

$\mathrm{CO2}_{it}$: Is the CO2 emission per person (Proxy for climate change at time t and individual i

FP_{it}: Food production

AVA_{it}: Agriculture valued added

L_{it}:Total labor force

K_{it}: Gross capital formation

Z_{it}: Are others control variables such as: crop production, livestock production, total fish production, food export, food import, and drought.

Aggregate output/economic growth/GDP per capital/real GDP is a function of the real capital stock (proxy variable Gross capital formation), labor (Labor force proxy), climate change (Proxy CO_2 emission), food production, and agriculture valued added. From Eq. 20.1, we get the following as adopted from Dell et al. (2008), Ceesay (2020), and Bond et al. (2010) and Belford et al. (2020):

$$Y_{it} = \mathrm{Ab}^{\alpha T_{it}} K_{it}^{\rho} L_{it}^{1-\rho-\sigma-\vartheta-\pi} FP_{it}^{\sigma} AVA_{it}^{\vartheta} Z_{it}^{\pi} e^{\varepsilon} \tag{20.2}$$

Such that: $\rho + \alpha + \sigma + \vartheta + \pi = 1$

$$\frac{\Delta \mathrm{A}_{it}}{\mathrm{A}_{it}} = g_i + \beta T_{it} \tag{20.3}$$

where Y is real GDP, L is labor (proxy labor force), A is technology and can also be referred to as labor productivity or total factor productivity, K is gross capital formation, T is the impact of climate change (CO2 emission proxy), g is the growth rate of capital, t is time period, e is exponential, and ε is a constant and it is also the error term in the model. Equation 20.2 captures the direct effect of climate change, food production, and agriculture value addition on economic growth, for example, effects on labor productivity, and Eq. 20.3 captures the indirect (dynamic) effect of climate change, for example, the effect of climate change on other variables that indirectly impacts GDP.

Presenting natural logarithm into Eq. 20.2 and deviating with respect to time, we derived Eq. 20.4 below:

$$g_{it} = g_i + (\alpha + \beta) T_{it} - \alpha T_{it-1} \tag{20.4}$$

where g_{it} is the growth rate of output; direct effects of climate change on economic growth are accounted for by α such as change in rainfall and temperature, and indirect effects are accounted for by β such as impact of climate change, flooding, or drought on other variables that indirectly influence GDP.

The study will observe both the direct and indirect effects of climate change, on agriculture value addition, and food production on the economic growth of The Gambia for the periods, observe given variations that will occur over time thus providing an insightful knowledge on which sector(s) is mostly affected under the following conditions: climate, agriculture, food production, and other factors that affect the economic growth in The Gambia.

20.3 Methodology

The data generated for this study was created from the World Development Indicators database for the period 1960–2017. The variables included are GDP (current \$), agriculture value added, crop production, livestock production, total fish production, food production (food availability proxy), food export, food import, average precipitation, and CO_2 emission per person (proxy for climate change). Food production is used as a proxy of one of the four dimensions of food security-food availability due to the following reasons: The first approach to food security is "food availability," because it is certainly the oldest one and still the most influential. Although the core ideas of this approach could be traced back to the Venetian thinker Giovanni Botero (1588), it was Thomas Malthus (1789) that popularized it and in datum it was known as the Malthusian theory of population and food. The method is focused on the (dis)equilibrium between population and food and in command to uphold this equilibrium the rate of growth of food availability should be not lower than the rate of growth of population and they should at least intersect to have food that satisfied the population growth. In a closed economy setting, this depends mainly on food production and stocks, while in an open economy also food trade can play a relevant role (Alkire 2002). Until the early 1970s, this was the reference approach for the international community, both at political and academic level. This was the main reasons why we selected the first dimension of food security as proxy for food production, that is, food availability.

20.3.1 Economic Model

The economic theory proposes models that explained the behavior of one or more variables, say $Y_1, Y_2, Y_3, \ldots\ldots\ldots\ldots, Y_n$ as a function of the some other variables, say $X_1, X_2, X_3, \ldots\ldots\ldots\ldots, X_m$ which are determined outside the model or which are exogenous in nature. In which we consider the following model, GDP (current \$) as a function of the following variables: labor force, gross capital formation, agriculture valued added, crop production, livestock production, total fish production, food production (food availability proxy), food export, food import, drought, and CO2 emission per person.

20.3.2 Econometric Model

In order to qualify the relationship between economic variables, it is necessary to propose a functional form that depends on some climate change variables or output variables and unknown parameters. The econometric model can be expressed as follows:

$Y = f(L, K, X_1, X_2, X_3, \ldots\ldots\ldots\ldots, X_k; \beta) + \varepsilon$, where β is a vector of unknown parameters and ε is the error term. The nature and the interpretation will depend on the assumption of the error term in the model.

20.3.3 Empirical Model

To assess the presence of food production (food availability), climate change, agriculture, and economic growth, the study adopted the empirical models as follows:

$$\begin{aligned}\text{LnGdp}_{it} &= \beta_0 + \beta_1\,\text{LnCrop}_{it} + \beta_2\,\text{LnFOSEC}_{it} + \beta_3\,\text{LnFish}_{it} + \beta_4\,\text{LnAr}_{it} \\ &+ \beta_5\text{LnCO2}_{it} + \beta_6\text{LnFoodEX}_{it} + \beta_7\text{LnFoodIM}_{it} + \beta_8\text{LnPop}_{it} + \varepsilon_{it}\end{aligned} \tag{20.5}$$

The variables above abbreviated below.

Ln Gdp_{it}= is the growth rate of Gdp at time t and individual i
LnCrop_{it}= is the growth rate of crop production at time t and individual i

LnFOSEC_{it}= the growth of Food production (proxy food availability) at time *t* and individual *i*
LnPop_{it}= growth rate of population
LnLiveS= growth rate of livestock
LnAr_{it}= growth rate of Agriculture at time *t* and *i*
LnCO2_{it}= growth of CO2 emission per capita at time *t* and individual *i*
LnFoodEX_{it}= growth of food export at time *t* and individual *i*
LnFoodIM_{it}= growth rate of food import at time *t* and *i*
LnFish_{it}= growth rate of fish production
ε_{it}= error term at time *t* and individual *i*
v_{it}= the country's unobserved fixed effect

When we added climate change variables, the model of the relationship between climate change, economics growth, food availability, and agriculture takes into account the following model:

$$\begin{aligned} \text{LnCLM}_{it} &= \beta_0 + \beta_1 \text{LnCrop}_{it} + \beta_2 \text{LnFOSEC}_{it} + \beta_3 \text{LnFish}_{it} \\ &+\beta_4 \text{LnAr}_{it} + \beta\_5 \text{LnFoodEX}\_it + \beta\_6 \text{LnFoodIM}\_it \\ &+\beta\_7 \text{LnPop}\_it + \beta\_8 \text{LnLiveS}\_ + \beta\_9 \text{ LnGdp}\_it + \varepsilon\_it \end{aligned} \tag{20.6}$$

The relationships food availability, agriculture, economic growth, and climate change look as the following model

$$\begin{aligned} \text{LnFOSEC}_{it} &= \beta_0 + \beta_1 \text{LnCrop}_{it} + \beta_2 \text{LnGdp}_{it} + \beta_3 \text{LnFish}_{it} + \beta_4 \text{LnAr}_{it} \\ &+\beta_5 \text{LnCLM}_{it} + \beta_6 \text{LnFoodEX}_{it} + \beta_7 \text{LnFoodIM}_{it} + \beta_8 \text{LnPop}_{it} + \beta_9 \text{LnLiveS} + \varepsilon_{it} \end{aligned}$$

NB. The variables of this chapter are logarithmized to allow the coefficients to be interpreted as elasticity, with all variables at time *t* and individual *i*.

20.3.4 Unit Root and Stationarity Tests

The time series is said to be stationary time series in weakly sense if its statistical properties do not vary with time (expectation, variance, autocorrelation). The white noise is an example of a stationary time series, with for example the case where Y_t follows a normal distribution N (μ, σ^2) independent of t. A non-stationary series can, for example, be stationary in first difference or so (also called integrated of order 1, 2, etc.): Y_t is not stationary, but the $Y_t - Y_{t-1}$ as first difference is stationary. Stationarity tests allow verifying whether a series is stationary or not at levels or first differences or second differences called integration of order 2. There are two different approaches about this, (1) stationarity tests such as the KPSS test that consider as null hypothesis H_0 that the series is stationary, and the alternative the series is not stationary and (2) unit root tests, such as the Dickey-Fuller test and its augmented version, the augmented Dickey-Fuller (ADF) test, or the Phillips-Perron (PP) test, for which the null hypothesis is on the contrary that the series has a unit root and hence is not stationary (Pesaran 2007).

To examine the long-run and short-run relationship among co-integration test of food production as a proxy for food security with economic growth, we develop the ARDL F-bound testing for co-integration following closely on the work of Menegaki (2019), which examined energy-growth nexus.

The ARDL equations of correlation between food production (food availability), climate change, agriculture, and economic growth nexus equations can be formulated as:

20.3.5 ARDL Model

$$\begin{aligned}\text{lnGDP} &= \alpha_0 + \sum_{i=1}^{p} \alpha_i \ \text{lnGDP}_{t-1} + \sum_{i=0}^{q} \beta_{1i} \ \text{lnCrop}_{t-1} + \sum_{i=0}^{p} \beta_{2i} \ \text{lnFOSEC}_{t-1} \\ &+ \sum_{i=0}^{p} \beta_{3i} \ \text{lnAgr}_{t-1} + \sum_{i=0}^{p} \beta_{4i} \ \text{lnCLM}_{t-1} + \sum_{i=0}^{p} \beta_{5i} \ \text{LnFoodEX}_{t-1} \\ &+ \sum_{i=0}^{p} \beta_{6i} \ \text{LnFoodIM}_{it\ t-1} + \sum_{i=0}^{p} \beta_{7i} \ \text{LnLiveS}_{t-1} + \lambda_1 \text{lnGDP}_{t-1} \\ &+ \lambda_2 \text{lnCrop}_{t-1} + \lambda_3 \text{lnFOSEC}_{t-1} + \lambda_4 \text{lnAgr}_{t-1} + \lambda_5 \text{lnCLM}_{t-1} \\ &+ \lambda_6 \text{lnFoodEX}_{t-1} + \lambda_7 \text{lnFoodIM}_{t-1} + \lambda_8 \text{lnLiveS}_{t-1} + \varepsilon..\end{aligned} \tag{20.7}$$

$$\begin{aligned}\text{lnFOSEC} &= \alpha_0 + \sum_{i=1}^{p} \alpha_i \text{lnFOSEC}_{t-1} + \sum_{i=0}^{q} \beta_{1i} \text{lnCrop}_{t-1} + \sum_{i=0}^{p} \beta_{2i} \text{lnGDP}_{t-1} + \sum_{i=0}^{p} \beta_{3i} \text{lnAgr}_{t-1} \\ &+ \sum_{i=0}^{p} \beta_{4i} \text{lnCLM}_{t-1} + \sum_{i=0}^{p} \beta_{5i} \text{LnFoodEX}_{t-1} + \sum_{i=0}^{p} \beta_{6i} \text{LnFoodIM}_{itt-1} + \sum_{i=0}^{p} \text{B}_{7i} \text{Ln Pop}_{t-1} \\ &+ \sum_{i=0}^{p} \beta_{8i} \text{LnLiveS}_{t-1} + \sum_{i=0}^{p} \beta_{9i} \text{LFish}_{t-1} + \lambda_1 \text{lnGDP}_{t-1} + \lambda_2 \text{lnCrop}_{t-1} + \lambda_3 \text{lnFOSEC}_{t-1} \\ &+ \lambda_4 \text{lnAgr}_{t-1} + \lambda_5 \text{lnCLM}_{t-1} + \lambda_6 \text{lnFoodEX}_{t-1} + \lambda_7 \text{lnFoodIM}_{t-1} + \lambda_8 \text{lnLiveS}_{t-1} \\ &+ \lambda_9 \text{LFish}_{t-1} + \varepsilon..\end{aligned} \tag{20.8}$$

Where β_1, β_2, β_3 β_4 , β_5 *and so on are* the coefficients that measure the short-run relationship while λ_1, λ_2, λ_3, λ_4, λ_5, λ_6*and so on* are the coefficients that measure the long-run relationship. To test for co-integration, we will use the bounded test that was proposed by Pesaran and Shin (1999) and Pesaran et al. (2001).

20.3.6 Error Correction Model

20.3.6.1 VECM (Vector Error Correlation Model) Model

Drawing on the work of Granger (1988), the causal link can be tested within the framework of Error Correction Model (ECM). ECM is connected with the multiple time series models typically realistic for the data when the primary variables have long-run stochastic trend that is often called as co-integration. ECMs compute the rate at which the variable of attention moves back towards the equilibrium after a variation in other variables and henceforth, characterize the short-run dynamics. We implement the Granger causality ECM test method in this study since it can treat both large and small sample sizes and therefore having a comparative advantage over the other traditional methods.

The Granger causality test based of VECM is thus determined by the following ARDL models:

$$\begin{aligned}\ln\text{GDP} &= \alpha_0 + \sum_{i=1}^{p}\alpha_i \ \ln\text{GDP}_{t-1} + \sum_{i=0}^{q}\beta_{1i} \ \ln\text{Crop}_{t-1} + \sum_{i=0}^{p}\beta_{2i}\ln\text{FOSEC}_{t-1} \\ &+ \sum_{i=0}^{p}\beta_{3i} \ \ln\text{Agr}_{t-1} + \sum_{i=0}^{p}\beta_{4i} \ \ln\text{CLM}_{t-1} + \sum_{i=0}^{p}\beta_{5i} \ \text{LnFoodEX}_{t-1} \\ &+ \sum_{i=0}^{p}\beta_{6i} \ \text{LnFoodIM}_{it\,t-1} + \sum_{i=0}^{p}\beta_{7i} \ \text{Lfish}_{t-1} + \sum_{i=0}^{p}\beta_{8i} \ \text{LnLiveS}_{t-1} + \ \text{ECM}_{t-1} + \varepsilon..\end{aligned} \tag{20.9}$$

$$\begin{aligned}\ln\text{FOSEC} &= \alpha_0 + \sum_{i=1}^{p}\alpha_i \ \ln\text{FOSEC}_{t-1} + \sum_{i=0}^{q}\beta_{1i} \ \ln\text{Crop}_{t-1} + \sum_{i=0}^{p}\beta_{2i} \ \ln\text{GDP}_{t-1} \\ &+ \sum_{i=0}^{p}\beta_{3i} \ \ln\text{Agr}_{t-1} + \sum_{i=0}^{p}\beta_{4i} \ \ln\text{CLM}_{t-1} + \sum_{i=0}^{p}\beta_{5i} \ \text{LnFoodEX}_{t-1} + \sum_{i=0}^{p}\beta_{6i} \ \text{LnFoodIM}_{it\,t-1} \\ &+ \sum_{i=0}^{p}\beta_{7i} \ \text{Lfish}_{t-1} + \sum_{i=0}^{p}\beta_{8i} \ \text{LnLiveS}_{t-1} + \text{ECM}_{t-1} + \varepsilon..\end{aligned} \tag{20.10}$$

where ECMt-1 represents lagged error-correction model term, which is derived from co-integration equation of ARDL, bound testing of co-integration.

According to Nida et al. (2018), in their paper, they used the ARDL bound testing method and found that along with a long-run relationship between the natural disasters and economic growth, there is also a unidirectional causality between these two variables. The causality between these variables cannot be determined without assessing the F-statistic and the lagged error-correction term. If we understand the Granger causality test very well, it is not difficult to know that if the F-statistic of the descriptive or explanatory variable is significant, then the short-run causal effects and long-run causal effects can be determined by the coefficient of the lagged error correlation term in the model. We have included ECMs in both Eqs. 20.9 and 20.10.

20.4 Econometric Results

The data for this study was generated from the World Development Indicators for the period 1960–2017. Table 20.1 shows the descriptive statistics for the variables used in the study. The natural logarithm of GDP has the highest mean, and it is associated with the highest standard deviation.

The correlation matrix is used to determine the relationship between two variables (Table 20.2). The Pearson correlation coefficient is used to represent this relationship, which ranges from −1.00 to +1.00. The results of the test of correlation show the relationship between the growth of crop production in the Gambia, and the GDP growth rate is slightly positive (a correlation coefficient of 0.17). Thus, if growth of crop production increases by 1%, growth rate of GDP rises by 0.17%. In the Gambia, due to lack of mechanization of agriculture, the growth of agriculture is negatively related to the growth of GDP (the correlation coefficient of −0.73). In addition, the growth of CO2 emission per person has a negative relationship with the growth of agriculture (Table 20.2).

The growth rate of GDP and the growth of food production (food availability proxy) are positively correlated with a correlation coefficient of 0.49. Finally, the growth of fish production in the Gambia is positively correlated with the GDP growth rate (with correlation coefficient of 0.92). Hence, if the growth of fish production increases by 1%, the growth rate of gross domestic product (GDP) increases by 0.92%. With this huge increase, the youth and the government of the Gambia should take advantage of the fish production as a means of not only enhancing the livelihood of Gambians but also as a means of boosting the country's economic growth. In Fig. 20.1, the growth of GDP fluctuated in the Gambia because the country's economy experienced some form of break point 1981 and 1995 when we estimated the break point date.

It can be seen from Fig. 20.1 that while the growth of food imports rises in the Gambia, the growth of agriculture decreases. This is due to the fact that the economy of the Gambia is import-based, and since the country's agriculture is not

Table 20.1 Descriptive statistics

Variables	No. of observation	Mean	Standard deviation
LnGDP	48	19.73	0.9853296
LnFoodImprot	48	3.469	0.1757662
LnFOSEC	48	4.321	0.2480349
LnLifesto	48	4.162	0.4286894
LnCO2	48	−0.9279	0.2045054
LnCrop	48	4.351	0.2576522
LnAg	48	3.237	0.1934821
LnFoodEX	48	4.402	0.2557106
LnFish	48	9.977	0.6102637

Source: Authors' computation, 2020

Table 20.2 Correlation matrix

Variables	LnGDP	LnCrop	LnAg	LnLifesto	LnFish	LnFOSEC	LnFoodEX	LnFoodImprot	LnCO2
LnGDP	1	0.17	−0.7	0.90	0.92	0.49	−0.56	0.72	0.60
LnCrop	0.17	1	0.30	0.36	0.35	0.92	0.01	0.18	o.11
LnAg	−0.73	0.30	1	−0.66	−0.58	−0.04	0.51	−0.56	−0.2
LnLifesto	0.90	0.36	−0.7	1	0.93	0.69	−0.46	0.71	0.39
LnFish	0.92	0.35	−0.6	0.93	1	0.65	−0.47	0.69	0.54
LnFOSEC	0.49	0.92	−0.0	0.69	0.65	1	−0.19	0.44	0.22
LnFoodEX	−0.56	0.01	0.51	−0.46	−0.47	−0.19	1	−0.41	−0.42
LnFoodImp	0.72	0.18	−0.6	0.71	0.69	0.44	−0.42	1	0.21
LnCO2	0.60	0.11	−0.2	0.39	0.54	0.22	−0.422	0.21	1

Source: Authors' computation, 2020

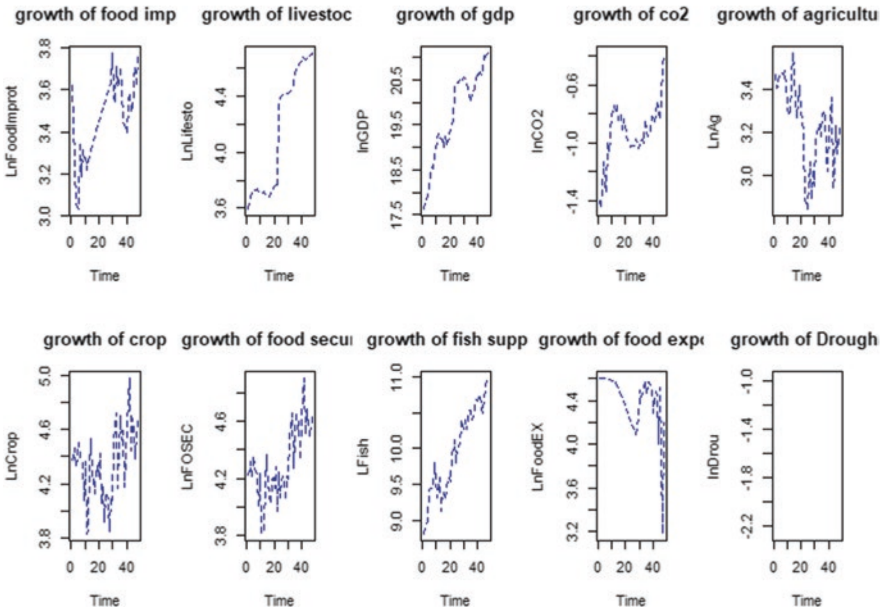

Fig. 20.1 The fluctuation of time series plot for the Gambia. (*Source*: Drawn by the authors using research data, 2020)

producing enough, the country imports the vast majority of the goods and services it needs.

On the other hand, the growth of export is falling and this can be attributed to the persistent decline in the growth of agricultural output.

The persistent falls in the growth rate of agricultural output have implications for food production because increased food production depends mostly on a growing agricultural sector. However, falling growth rates in agriculture is offset by the growth rates in both fish and livestock production (Fig. 20.1).

Table 20.3 presents the results of Augmented Dickey-Fuller (ADF) test, Phillips-Perron (PP) test, and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test for all variables in levels and first differences using the time series annual data from 1960 to 2017. The results confirmed that the null hypothesis of unit root at the 5%, 1%, and 10% critical values for all series can be rejected, except for growth rate of GDP, growth of fish production, growth of CO2, and growth of livestock for ADF test only. Yet, the null hypothesis is rejected at different percentage levels of the critical value for the series in the first difference and in the levels. The results in Table 20.3 show that there is a combination of I (0) and I (1) of the regressions in the models. Hence, it is appropriate to use the ARDL and ECM approaches for the analysis. The lag length is selected using the minimum values of AIC criteria, which shows the smaller the AIC, the better for the model. This finding is consistent with the results from the study done by Shrestha and Chowdhury (2005). The optimal lag for the model is 3. The study also applied the VAR Granger with lag 3 as well, because at

Table 20.3 Unit root test

Variable	ADF		PP		KPSS	
	Level	1st Diff.	Level	1st Diff.	Level	1st Diff.
LnGDP	0.055*	0.075*	0.055***	0.000***	0.662***	0.357***
LnCrop	0.001***	0.001***	0.001***	0.000***	0.393***	0.273***
LnAg	0.018**	0.019**	0.019***	0.000***	0.439***	0.261***
LnLifesto	0.312	0.398	0.312***	0.000***	0.387***	0.214**
LnFish	0.180	0.216	0.180***	0.000***	0.159**	0.103
LnFOSEC	0.013**	0.013**	0.013***	0.000***	0.456***	0.315***
LnFoodEX	0.001***	0.001***	0.001***	0.000***	0.201***	0.141*
LnFoodImp	0.068*	0.069*	0.068***	0.000***	0.286***	0.185***
LnCO2	0.302	0.174	0.302***	0.000***	0.433***	0.247***

Source: Authors' computation, 2020
NB: *, **, and *** are statistically significant at 10%, 5%, and 1%, respectively

some point, the series are not stationary, and the study needs to transform the model into stationary time series.

20.4.1 ARDL Analysis

The ARDL analysis is carried out based on the results in Table 20.4. In the end, growth of crop production in the Gambia has a positive effect on the growth of GDP. From Table 20.4, it can be seen that a 1% increase in growth of crop production, increases the growth of GDP by 0.054%.

In our study, it was revealed that, the growth rate of GDP and the growth of food production are positively correlated with a correlation coefficient of 0.49 in the Gambia. This is due to the fact that in the dry seasons crop production by Gambians helps to contribute to the growth of GDP by a very small amount due to traditional method of gardening.

Furthermore, the study also confirmed that using ARDL framework, growth of food production (food availability proxy) in the Gambia negatively affects the growth of GDP by 0.0731% in the end. The possible reasons underlying such result is because the coefficients of the growth of agriculture are negative in both the short run and long run. Agriculture being the backbone of the economy of the Gambia, insufficient food production affects the entire economy, including the consumption of agricultural produce. In both the short run and long run, growth in fish production and livestock in the Gambia has positive impacts on the growth of GDP. This finding is supported by the anecdotal evidence, which suggests that Gambian youth are increasingly getting involved in the livestock and fish production, which in turn helps boost the economy of the Gambia. The world in general and the Gambia in particular, due to the unachievability of certain SDGs such as poverty (SDG no. 1), hunger (SDG no. 2), and climate change (SDG no. 13), the world is still facing starvation, conflict, insufficient water supply and food production, malnutrition, and

Table 20.4 ARDL model: Growth of GDP as dependent variable

Coefficients:

(Intercept)	L(lnGDP, 1)	L(lnGDP, 2)
6.15948	0.68322	0.04436
LnCrop	L(LnCrop, 1)	LnFOSEC
0.60489	0.86721	-0.96455
L(LnFOSEC, 1)	LnFoodEX	L(LnFoodEX, 1)
-1.02775	0.00416	-0.18617
LnAg	L(LnAg, 1)	LnFoodImprot
-0.11069	-0.33833	-0.03870
L(LnFoodImprot, 1)	LFish	L(LFish, 1)
-0.26347	0.12530	0.14049
LnLifesto	L(LnLifesto, 1)	InCO2
1.14634	-0.61730	0.02711
L(InCO2, 1)		
0.06269		

Long-term coefficients:

LnCrop	LnFOSEC	LnFoodEX	LnAg	LnFoodImprot	LFish
5.4039057	-7.3134727	-0.6681408	-1.6483059	-1.1092028	0.9756745
LnLifesto	InCO2				
1.9420084	0.3296430				

Short-term coefficients

(Intercept)	L(d(lnGDP))	d(LnCrop)	d(LnFOSEC)
6.159483247	-0.044360790	0.604894088	-0.964553183
d(LnFoodEX)	d(LnAg)	d(LnFoodImprot)	d(LFish)
0.004160399	-0.110689343	-0.038696259	0.125297521
d(LnLifesto)	d(InCO2)	L(coint)	
1.146336012	0.027113296	-0.272415263	

Own evaluation

Source: Authors' computation, 2020

poor agricultural practices. In their part, according to Manap and Ismail (2019) wrote on Food Security and EconomicGrowth nexus confirmed that food security has an impact on economic growth, especially in dry-land developing countries. Their study revealed that an increase in food security results in an increase in economic growth.

In terms of the impact of the growth of average precipitation and CO_2 emission (proxy for climate change) on the growth of GDP, the findings in Table 20.4 has shown this to have a positive impact on the Gambian economy. This is consistent with the study done by Cederborg and Snöbohm (2016) confirmed in their study that empirical result of the cross-sectional study implies that, there is in fact a relationship between per capita GDP and per capita carbon dioxide emissions. It shows positive correlation, which suggests that, growing per capita GDP leads to increasing carbon dioxide emissions. In contrast to the study done by (Ali et al. 2019) in which they wrote a paper on Analysis of the Nexus of CO_2 Emissions, Economic

Growth, Land under Cereal Crops, and Agriculture Value-Added in Pakistan using an ARDL approach confirmed in their results of the short-run ARDL analysis, which pointed out that there is a negative and statistically insignificant association between carbon dioxide emissions and gross domestic product in Pakistan. In most of the developed world, the higher the country's emission into the atmosphere, the higher the GDP growth.

On the other hand, the growth of agriculture and the growth of food import have negative effects on the growth of GDP in both the short run and in the long run. This is why the importation of food products rises in the Gambia, with traditional ways of agriculture increasing.

Table 20.4 further shows that the growth of food export has positive effect on growth of GDP in the short run and negative effect on the growth of GDP in the long run.

Table 20.5 shows that in the long run, the following variables have positive effects on the growth of food production in the Gambia: the growth of agriculture, the growth of crop production, and the growth of livestock production. This means that for the economy of the Gambia to grow, the government needs to develop policies that are geared towards the growth in crop, livestock, and agriculture if the country's food production is to be enhanced.

In the short run, however, the following variables have positive effects on the growth of food production in the Gambia: growths in crop production, food imports, and growth of CO_2 emission per person.

On the other hand, the following variables have both short and long run positive impacts on the growth of food production in the Gambia: growths in both crop and livestock production. It can be observed in Table 20.5 that the following variables have both short and long run negative impacts on the growth of food production in the Gambia: GDP growth, growth of food export, and growth of fish production.

The following variables have mixed impacts on the growth of food production in the Gambia: growth of agriculture has long-run positive impact but in the short run, the impact is negative. In terms of growth of food import and the growth of CO_2, evidence from Table 20.5 shows that these have positive effects in the short run, but long-run negative impacts.

Figure 20.2 indicates that there is a negative relationship between agriculture and the growth of GDP in the Gambia as illustrated by the regression line. This means that the sum of the squares of the residual and the sum of squares is explained by the regression has large errors. The outliers from minimum values to maximum values are large and that downward sloping has inverse relationship between the growth of agriculture and growth of GDP. Time series trend for growth of fish production in the Gambia has an upward trend from 1960 to 2017 as illustrated below.

Table 20.5 ARDL model: Growth of food production as dependent variable

```
Coefficients:
       (Intercept)       L(LnFOSEC, 1)       L(LnFOSEC, 2)
         0.2399884           0.1510273          -0.0146739
            LnCrop        L(LnCrop, 1)               lnGDP
         0.7381121          -0.1163428          -0.0134743
       L(lnGDP, 1)            LnFoodEX      L(LnFoodEX, 1)
         0.0111288          -0.0118260          -0.0111311
              LnAg          L(LnAg, 1)        LnFoodImprot
        -0.0109250           0.0322370           0.0003437
L(LnFoodImprot, 1)               LFish         L(LFish, 1)
        -0.0434347          -0.0007265          -0.0025158
         LnLifesto     L(LnLifesto, 1)               InCO2
         0.2634889          -0.0213961           0.0205244
       L(InCO2, 1)
        -0.0613253

Long-term coefficients:
      LnCrop        lnGDP     LnFoodEX         LnAg LnFoodImprot        LFish
 0.719934867 -0.002715779 -0.026581668  0.024676685 -0.049894245 -0.003754158
   LnLifesto        InCO2
 0.280314589 -0.047242559

 Short-term coefficients
    (Intercept)   L(d(LnFOSEC))       d(LnCrop)        d(lnGDP)
   0.2399884403    0.0146738772    0.7381121111   -0.0134742544
    d(LnFoodEX)         d(LnAg) d(LnFoodImprot)        d(LFish)
  -0.0118260471   -0.0109250168    0.0003437137   -0.0007264964
   d(LnLifesto)        d(InCO2)        L(coint)
   0.2634888694    0.0205243998   -0.8636465732
Own Evaluation using Statistical Software-R
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Source: Authors' computation, 2020

20.4.2 Vector Autoregressive (VAR) Results

The Vector autoregressive (VAR) results are shown in Table 20.6. Before applying the Granger causality test, the study first applied the VAR model with optimal lag of 3 based on AIC criteria, which indicates that the lower the lags, the better. As the results generated in Table 20.6 indicate, the p-value of growth of crop production is significant at lag 1 and lag 2 and not significant at lag 3. Both lags 1 and 2 have significant positive impacts on the growth of GDP. The growth of agriculture is not statically significant at all in both lags and has negative coefficient at lag 2. Growth of livestock and growth of fish production has significant impacts on the growth of GDP at lag 2. The third lag for growth of livestock and growth of food production does not have causality impact on the growth of GDP. The growth of food production in the Gambia has statistically significant negative impacts on the growth of GDP. Growth of food export is highly significant at lag 1 and lag 3 while growth of

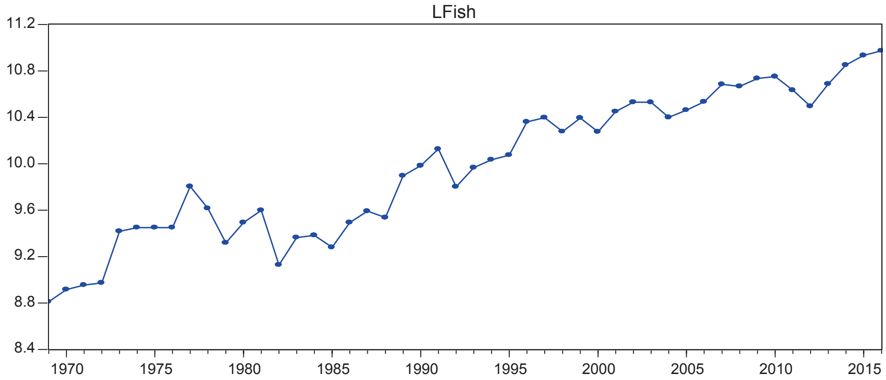


Fig. 20.2 The time series graph for the growth of fish production in the Gambia from 1960 to 2017. (Source: Drawn by the authors using research data, 2020)

food import is significant at lag 1, 2, and 3. The growth of climate change is also significant at lag 1 and lag 3.

As Fig. 20.3 shows, the mean point – the yellow dot at the center of the distribution – confirmed that the linearity between the growth of economy and the growth of agriculture value added in the Gambia has a downward slope. This negative influence of the variables in question confirmed that growth of agriculture value added does not cause growth of economy, the study asserted.

In Fig. 20.4, the growth of climate change and the growth of GDP have a positive relationship, which suggests that in the Gambia, as climate change (CO_2 emission) grows, the economy of the Gambia also grows.

In Fig. 20.5, the fluctuation of climate change in the Gambia over the period from 1960 to 2017 is stationary, because the series fluctuate around its mean. The *p*-values are statistically significant for the periods 1981, 1995, and 2017. Climate change is also expected to grow in the near future as indicated below (Figs. 20.6 and 20.7).

The growth of food imports in the Gambia from 1980 to 1999 has a constant trend. It means those years' agriculture was good in the Gambia, because the government does not spend much on food importation. Import of good and services cost the economy to grow negatively and the growth of food import in the near future has a negative sign, and until policy recommendation about agriculture is taken into account, the Gambia may experience food import for some time from now.

20.4.3 Granger Causality Test

The objective of applying the VAR Granger Causality test is to verify whether there is a causal relationship between the different variables in our empirical investigation. The causality test indicates that the following variables Granger cause the

Table 20.6 Vector Autoregressive (VAR) Model results

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnGDP						
lnGDP						
L1.	.3731046	.1645772	2.27	0.023	.0505392	.69567
L2.	-.0330973	.1713371	-0.19	0.847	-.3689119	.3027172
L3.	.0488529	.1252563	0.39	0.697	-.1966449	.2943508
LnCrop						
L1.	1.809103	1.060869	1.71	0.088	-.2701612	3.888368
L2.	3.098078	1.299605	2.38	0.017	.5508995	5.645256
L3.	.7990732	1.035377	0.77	0.440	-1.230228	2.828374
LnAg						
L1.	.035934	.2663744	0.13	0.893	-.4861502	.5580181
L2.	-.3081255	.2233653	-1.38	0.168	-.7459134	.1296624
L3.	.0079202	.2450537	0.03	0.974	-.4723762	.4882166
LnLifesto						
L1.	.2104039	.4637054	0.45	0.650	-.6984421	1.11925
L2.	.931723	.5377544	1.73	0.083	-.1222562	1.985702
L3.	.3757485	.4513716	0.83	0.405	-.5089237	1.260421
LFish						
L1.	.0804297	.1284161	0.63	0.531	-.1712612	.3321206
L2.	.6860993	.1325978	5.17	0.000	.4262124	.9459862
L3.	.3277848	.1567165	2.09	0.036	.020626	.6349435
LnFOSEC						
L1.	-2.763284	1.414276	-1.95	0.051	-5.535213	.0086458
L2.	-4.084052	1.782151	-2.29	0.022	-7.577005	-.5910994
L3.	-.9667313	1.403347	-0.69	0.491	-3.717242	1.783779

Own evaluation

Authors' computation, 2020

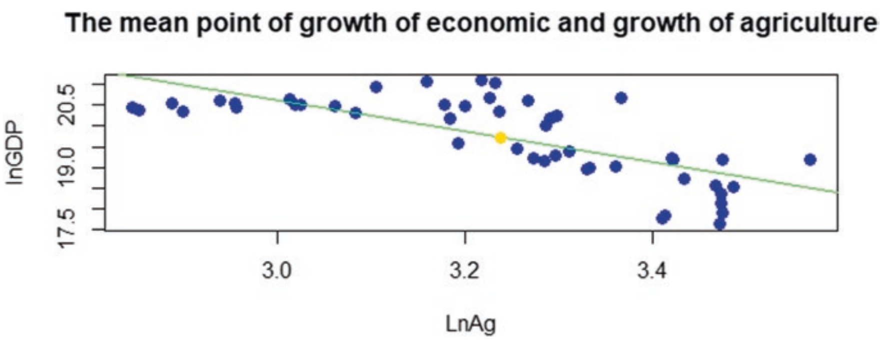


Fig. 20.3 The mean point of economic growth and agricultural growth. (Source: Drawn by the authors using research data, 2020)

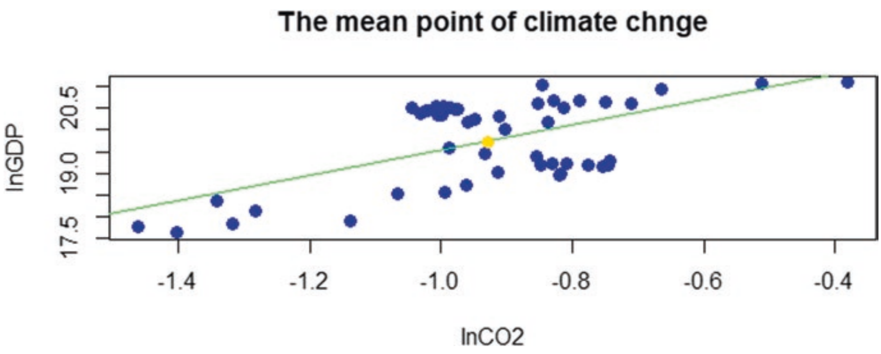


Fig. 20.4 The mean point of climate change and economic growth. (Source: Drawn by the authors using research data, 2020)

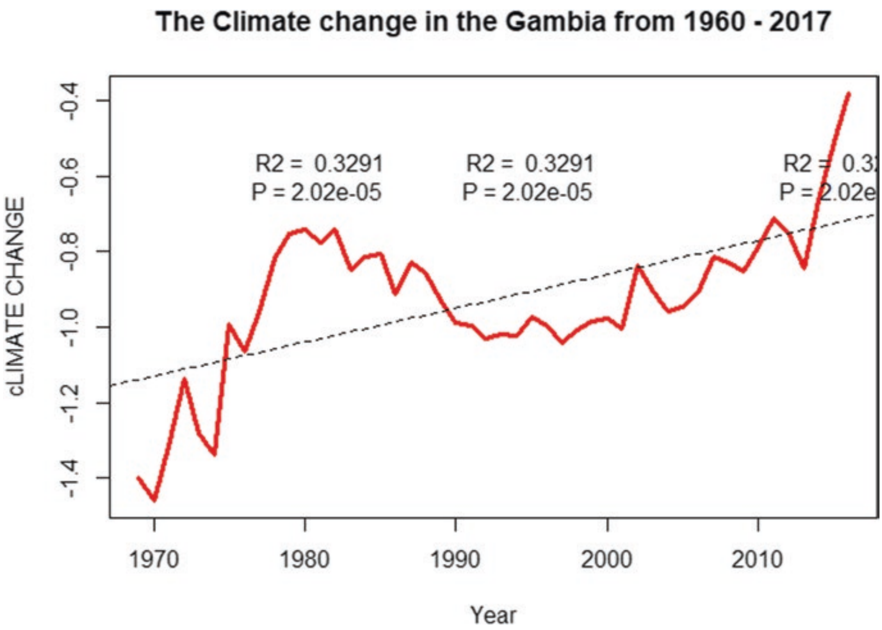


Fig. 20.5 Time series plot for climate change in the Gambia. (Source: Drawn by the authors using research data, 2020)

growth of GDP in the Gambia: the growth of crop production, growth of fish production, growth of food production, growth of food export, growth of food imports, and growth of CO_2 (Table 20.7) (Fig. 20.8).

The results in Table 20.7 show a surprising picture as the growth of agriculture and the growth of livestock does do not Granger cause the growth of GDP. However, the following variables Granger cause the growth of food production: growth of crop production, growth of agriculture, growth of livestock, growth of fish

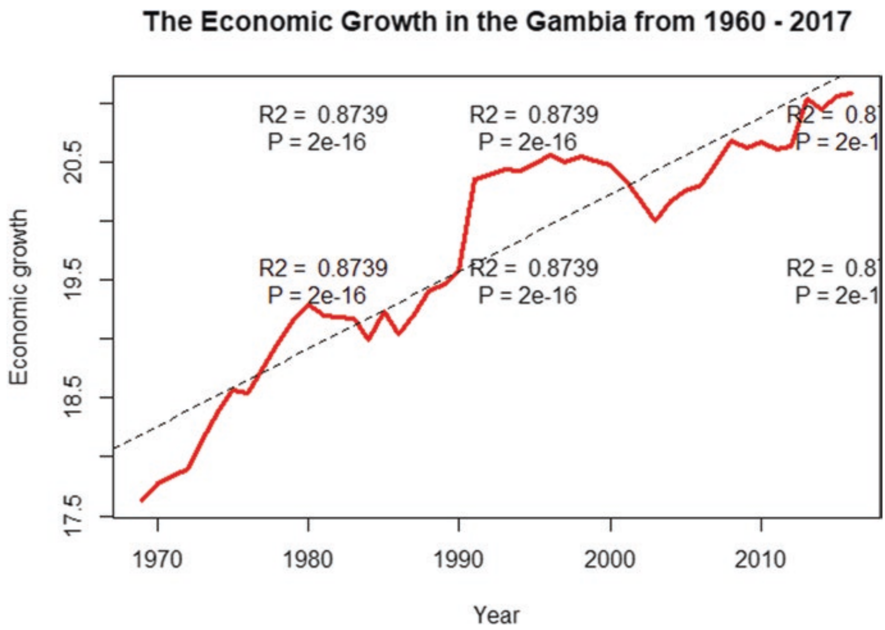


Fig. 20.6 The Trajectory of Economic Growth in The Gambia From 1960 to 2017. (Source: Drawn by the authors using research data, 2020)

production, growth of food export, and growth of CO2. Nevertheless, the growth of GDP and growth of food import does not Granger cause growth of food production in the Gambia. These results are shown in Table 20.7.

From Table 20.8, it can be seen that the growth of GDP does not Granger cause growth of crop production but growth of crop production Granger causes growth of GDP, which is a unidirectional relationship. On the other hand, the growth of agriculture Granger causes growth of crop production, and growth of crop production Granger causes the growth of agriculture in the Gambia, which shows a bidirectional relationship between these variables. In fire8, the growth of economy and the growth agriculture is in opposite direction (Fig. 20.9).

The following variables Granger cause the growth of crop production and at the same time Granger cause the growth of agriculture in the Gambia: growth of livestock, growth of fish production, growth of food production, growth of food export, and growth of CO2.

The growth of food import does not Granger cause the growth of crop production (Table 20.8). The result is not significant statistically; this is true because the country is indebted through importing rather than exporting. Furthermore, according to Ceesay et al. (2019), export does not cause growth in the Gambia. Total imports Granger caused growth and growth Granger caused import in the Gambia (Ceesay et al. 2019). Growth of food import and growth of GDP does not cause growth of

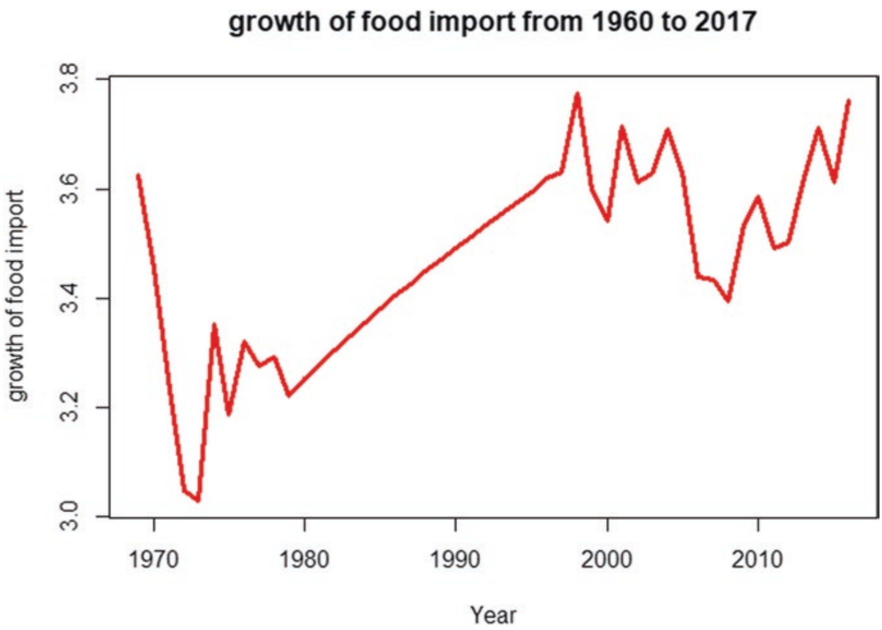


Fig. 20.7 The trajectory of growth in food import in the Gambia. (Source: Drawn by the authors using research data, 2020)

Table 20.7 Granger causality test results

Equation	Excluded	Direction	*P*-value	Equation	Excluded	Direction	*P*-value
LnGDP	LnCrop	DI	0.006***	LnFOSEC	LnGDP	INDI	0.244
LnGDP	LnAg	INDI	0.576	LnFOSEC	LnCrop	DI	0.024**
LnGDP	Lnlifestock	INDI	0.113	LnFOSEC	LnAg	DI	0.024**
LnGDP	LnFish	DI	0.000***	LnFOSEC	Lnlifestock	DI	0.014***
LnGDP	LnFOSEC	DI	0.008***	LnFOSEC	LnFish	DI	0.026**
LnGDP	LnFoodEX	DI	0.000***	LnFOSEC	LnFoodEX	DI	0.043**
LnGDP	LnFoodImport	DI	0.001***	LnFOSEC	LnFoodImp	INDI	0.506
LnGDP	LnCO2	DI	0.001***	LnFOSEC	LnCO2	DI	0.018**
LnGDP	Overall	DI	0.000***	LnFOSEC	Overall	DI	0.000***

Source: Authors' computation, 2020
NB. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Note DI is direct/granger, INDI is indirect/not granger

crop production, because budget from the GDP is used for the importation and not for production of crops in the Gambia.

From Table 20.9, it is clear that the growth of crop production does not influence the growth of livestock. The result is indirect. Growth of GDP does not cause growth of livestock and growth of livestock does not Granger cause the growth of GDP-unidirectional relationship. Growth of agriculture causes livestock and growth of livestock significantly causes growth of agriculture-bidirectional relationship.

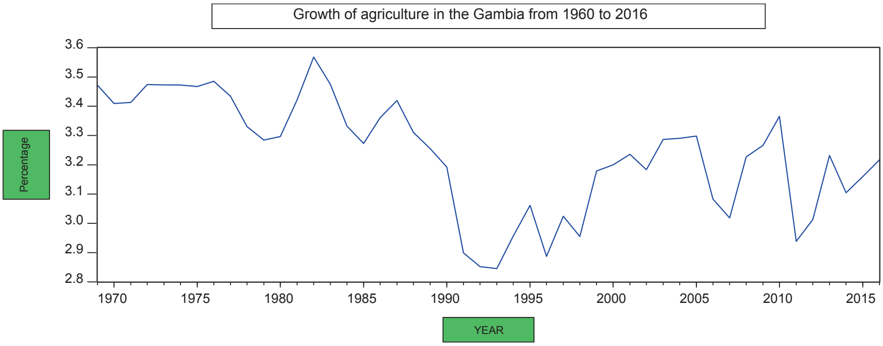


Fig. 20.8 The trajectory of agricultural growth in the Gambia. (Source: Drawn by the authors using research data, 2020)

Table 20.8 Granger causality test results

Equation	Excluded	Direction	*P*-value	Equation	Excluded	Direction	*P*-value
LnCrop	LnGDP	INDI	0.276	LnAg	LnGDP	DI	0.001***
LnCrop	LnAg	DI	0.050**	LnAg	LnCrop	DI	0.000***
LnCrop	Lnlifestock	DI	0.008***	LnAg	LnFOSEC	DI	0.000***
LnCrop	LnFish	DI	0.072*	LnAg	Lnlifestock	DI	0.000***
LnCrop	LnFOSEC	DI	0.008***	LnAg	LnFish	DI	0.014***
LnCrop	LnFoodEX	DI	0.026**	LnAg	LnFoodEX	DI	0.000***
LnCrop	LnFoodImport	INDI	0.629	LnAg	LnFoodImp	INDI	0.000***
LnCrop	LnCO2	DI	0.014***	LnAg	LnCO2	DI	0.000***
LnCrop	Overall	DI	0.001***	LnAg	Overall	DI	0.000***

Source: Authors' computation, 2020
N.B. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Note DI is direct/granger, INDI is indirect/not granger

Growth of fish Granger causes growth of livestock and growth of livestock is also a leading significant positive influence to the growth of fish production-bidirectional. Growth of livestock causes food production but food production does not cause growth of livestock-unidirectional. Growth of livestock and growth of food export does not influence each other-indirect.

In the Gambia, because of poor agriculture, livestock production only benefits local farmers but is not exported to other countries to drive revenue and to boost economic growth. Growth of CO2 is an important variable for growth of livestock. There is a bidirectional relationship between growth of food import to growth of livestock and growth of livestock to growth of food import-bidirectional relationship. Growth of GDP does not Granger cause growth of fish production, but growth of fish production Granger causes growth of GDP-unidirectional relationship. The policy maker should look at the production of fish as an important indicator to the growth of GDP in the Gambia. There is a bidirectional relationship between the growth of agriculture and the growth of fish production. This is because fish production is part of improvement in agricultural activities. Growth of CO2 Granger causes

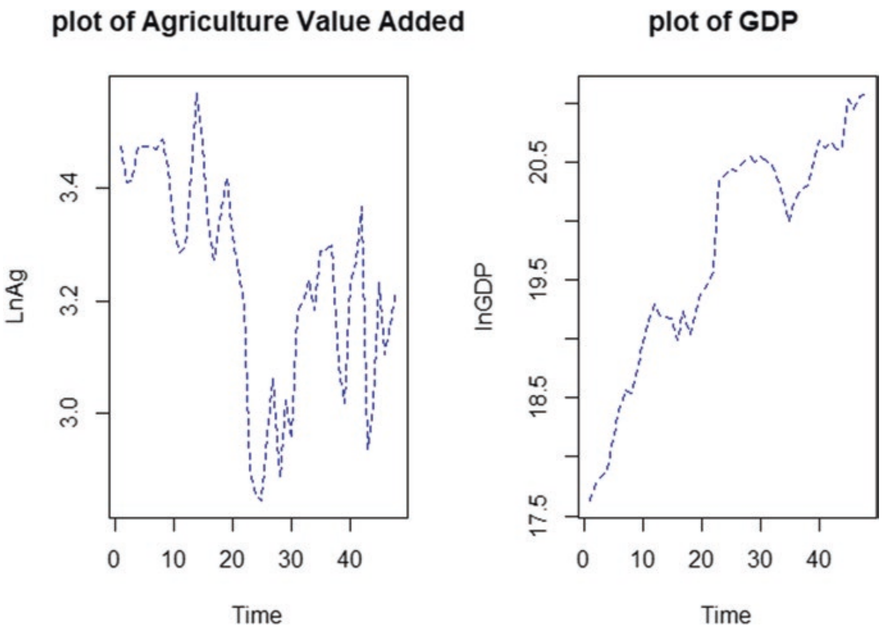


Fig. 20.9 Plot of GDP (right) and plot of agriculture (left). (Source: Drawn by the authors using research data, 2020)

Table 20.9 Granger causality test results

Equation	Excluded	Direction	*P*-value	Equation	Excluded	Direction	*P*-value
Lnlifestock	LnCrop	INDI	0.114	LnFish	LnGDP	INDI	0.200
Lnlifestock	LnAg	DI	0.054**	LnFish	LnCrop	DI	0.063*
Lnlifestock	LnGDP	INDI	0.601	LnFish	LnAg	DI	0.001***
Lnlifestock	LnFish	DI	0.000***	LnFish	Lnlifestock	DI	0.082*
Lnlifestock	LnFOSEC	INDI	0.134	LnFish	LnFOSEC	DI	0.080*
Lnlifestock	LnFoodE	INDI	0.243	LnFish	LnFoodEX	DI	0.005***
Lnlifestock	LnFoodIm	DI	0.020**	LnFish	LnFoodImp	DI	0.020**
Lnlifestock	LnCO2	DI	0.006***	LnFish	LnCO2	DI	0.039**
Lnlifestock	Overall	DI	0.000***	LnFish	Overall	DI	0.000***

Source: Authors' computation, 2020
N.B. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Note DI is direct/Granger, INDI is indirect/not Granger

the growth of both fish production and livestock production in the Gambia. Together, growth of food export and growth of food import both Granger cause the growth of fish production. Fish production Granger causes food production and food production also Granger causes fish production-bidirectional relationship. These results are shown in Table 20.9 above.

From Table 20.10 shows the unidirectional relationships between the growths of crop production to growth of food import; but a bidirectional relationship between growth of agriculture to growth of food import and growth of food import to growth

Table 20.10 Granger causality test results

Equation	Excluded	Direction	*P*-value	Equation	Excluded	Direction	*P*-value
LnFoodImport	LnCrop	INDI	0.343	LnCO2	LnGDP	INDI	0.000***
LnFoodImport	LnAg	DI	0.005***	LnCO2	LnCrop	INDI	0.178
LnFoodImport	Lnlifestock	DI	0.030**	LnCO2	LnAg	INDI	0.893
LnFoodImport	LnFish	DI	0.014***	LnCO2	Lnlifestock	INDI	0.178
LnFoodImport	LnFOSEC	DI	0.238	LnCO2	LnFish	DI	0.086*
LnFoodImport	LnFoodEX	DI	0.010***	LnCO2	LnFoodE	INDI	0.128
LnFoodImport	LnGDP	DI	0.001***	LnCO2	LnFoodI	DI	0.000***
LnFoodImport	LnCO2	DI	0.000***	LnCO2	LnFOSEC	INDI	0.172
LnFoodImport	Overall	DI	0.000***	LnCO2	Overall	DI	0.000***

Source: Authors' computation, 2020
N. B: * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Note DI is direct/Granger, INDI is indirect/not Granger

Table 20.11 Granger causality test results

Equation	Excluded	Direction	*P*-value
LnFoodEX	LnGDP	DI	0.000***
LnFoodEX	LnAg	DI	0.000***
LnFoodEX	Lnlifestock	INDI	0.216
LnFoodEX	LnFish	DI	0.000***
LnFoodEX	LnFOSEC	DI	0.038**
LnFoodEX	Lncrop	INDI	0.152
LnFoodEX	LnFoodImport	DI	0.000***
LnFoodEX	LnCO2	DI	0.000***
LnFoodEX	Overall	DI	0.000***

Source: Authors' computation, 2020
N. B: * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Note DI is direct/Granger, INDI is indirect/not Granger

of agriculture. Growth of livestock and growth of fish production is a leading indicator for the growth of food import.

A very important finding is that growth of food production does not Granger cause growth of food import. Growth of food export together with the growth of GDP Granger causes growth in food import. Growth of CO_2 Granger causes growth in food import and growth of food import Granger causes growth of CO_2. Growth of CO_2 Granger causes GDP and growth of GDP Granger causes CO_2, which shows a bidirectional relationship. The following variables do not Granger cause CO_2: the growth of crop production, growth of agriculture, growth of fish production, and growth of food export.

The results in Table 20.11 below indicate that the following variables are leading indicators of growth of food export: growth of GDP, growth of agriculture, growth of fish production, growth of food production, growth of food import, and growth the of CO_2 emission.

Both the growth of crop production and the growth in livestock production do not Granger cause the growth in food export. This is due to the fact that agriculture is not a leading indicator for the growth of GDP in the Gambia.

20.4.4 Econometric Tests

Ramsey Reset Test for specification

The hypothesis test is as follows:

H0: the model is well specified (the model has no omitted variables).
Ha: the model is poorly specified (the model has omitted variables).

The Ramsey Reset test is a test of omitted variables.

If the null hypothesis is rejected, then there are omitted variables whose integration would improve the estimate. In this case, we can conclude that the model is poorly specified.

After having estimated the parameters by the least ordinary squares method

Ramsey Reset Test			
Equation: UNTITLED			
Specification: LNGDP LNCO2 LNFISH LNFOODEX LNAG LNCROP			
LNFOODIMPROT LNFOSEC LNLIFESTO			
Omitted Variables: Powers of fitted values from 2 to 4			
	Value	df	Probability
F-statistic	37.01	(3, 37)	0.0000
Likelihood ratio	66.55	3	0.0000

Source: Authors' computation, 2020

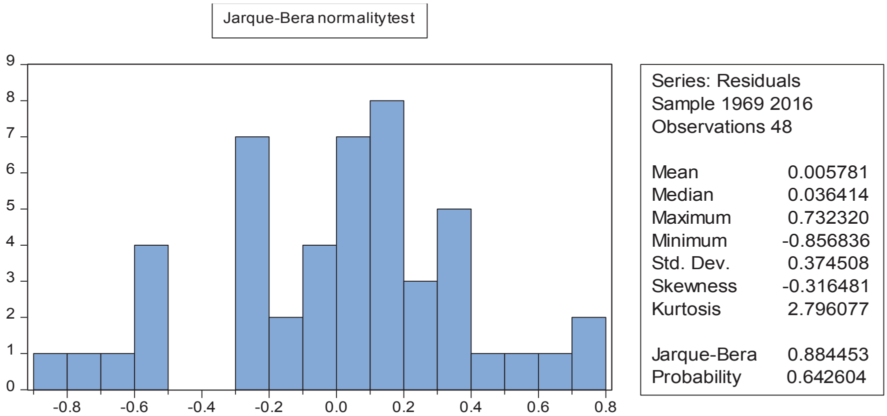
The Ramsey statistics (F-statistic) of 37.01 has a p-value of 0.0000. The model is well specified at the 0.01 level because $p = 0.000 > 0.01$. Note: Why the choice of 3 for "Number of fitted terms"? The conclusion reached by Thursby and Schmidt (1977) who carried out an extensive Monte Carlo exercise is that the value 3 seems to be generally the best choice.

20.4.5 Jarque-Bera Normality Test

The hypothesis test is as follows:

H0: the errors of the model follow a normal law of parameters μ and σ.
Ha: the errors of the model do not follow a normal law of parameters μ and σ.

After having estimated the parameters by the OLS



Source: Authors' computation, 2020

The Jarque-Bera statistic of 0.8845 has a *p*-value of 0.6426. The residuals of the model follow a normal law at the 0.05 level because $p = 0.8845 > 0.05$.

20.4.6 Heteroskedasticity Tests

20.4.6.1 White Test

The hypothesis test is as follows:

H_0: if errors of the model are homoscedastic (the errors have the same variance).
H_a: if errors of the model are heteroskedastic (the errors have different variances).
There are two options for the White Test.

Option 1: No Cross Terms

After having estimated the parameters by the OLS

Heteroscedasticity Test: White			
F-statistic	0.386897	Prob. F(4,43)	0.8168
Obs*R-squared	1.667525	Prob. Chi-Square(4)	0.7966
Scaled explained SS	2.908828	Prob. Chi-Square(4)	0.5732

Source: Authors' computation, 2020

The White statistic (Obs*R-squared) of 1.6675 has a *p*-value of 0.7966. The errors of the model are homoscedastic at the 0.05 level because $p = 0.7966 > 0.05$.

The White test is a Lagrange multiplier (LM) test. The Lagrange multiplier statistic is nR^2 where n is the number of observations or sample size.

Option 2: Include Cross Terms

Heteroscedasticity Test: White			
F-statistic	0.93952	Prob. F(10,37)	0.5097
Obs*R-squared	9.720179	Prob. Chi-Square(10)	0.4654
Scaled explained SS	16.95587	Prob. Chi-Square(10)	0.0753

Source: Authors' computation, 2020

The White statistic (Obs*R-squared) of 9.7202 has a p-value of 0.4654. The errors of the model are homoscedastic at the 0.05 level because $p = 0.4654 > 0.05$. Both the two options' results indicated the model is free from heteroscedasticity.

20.5 Discussion

Results from our findings revealed that growth of CO_2 emission per person (Proxy for climate change in our model) has a positive influence on the growth of GDP in the economy of the Gambia. Cederborg and Snöbohm (2016) confirmed in their study that empirical result of the cross-sectional study implies that there is in fact a relationship between per capita GDP and per capita carbon dioxide emissions. It shows positive correlation which suggests that growing per capita GDP leads to increasing carbon dioxide emissions. In contrast to the study done by Ali et al. (2019) in which they wrote a paper on Analysis of the Nexus of CO2 Emissions, Economic Growth, Land under Cereal Crops and Agriculture Value-Added in Pakistan using an ARDL Approach confirmed in their results of the short-run ARDL analysis, which pointed out that there is a negative and statistically insignificant association between carbon dioxide emissions and gross domestic product in Pakistan. In most of the developed world, the higher the country's CO_2 emission into the atmosphere, the higher the GDP growth.

In the Gambia, agricultural sector that includes production, in fish, livestock, forestry and hunting, crop, and so on serves as the backbone of the economy. In our results, it was pointed out that economic growth and growth in agriculture value addition in the Gambia shows a downward slope. This negative correlation may be attributed to the suggestion that agricultural funds are being diverted and do not reach the farmers to adopt new ways in agricultural practices, such as adaptation, mitigation, and resilience, a way of improving agricultural productivity. This is confirmed in the study done by Ceesay (2020) confirmed that economic growth has significant and negative force on employment in agriculture in general and with 10% rise in economic growth employment in agriculture in general is reduces by 0.05%. Another study conducted by (Belford et al., 2020) confirmed that In Anglophone West African countries, the growth rate of the agricultural sector and temperature are statistically significant and have a negative impact on the growth rate of GDP.

In our study, it was revealed that, the growth rate of GDP and the growth of food production are positively correlated with a correlation coefficient of 0.49 in the Gambia. Furthermore, the study also confirmed that using ARDL framework, Growth of food production in the Gambia negatively affects the growth of GDP by 0.0731% in the long run. This is because the coefficients of the growth of agriculture are negative in both the short run and long run. Agriculture being the backbone of the economy of the Gambia, insufficient food production affects the entire economy, including the consumption of agricultural produce. In both the short run and long run, growth in fish production and livestock in the Gambia have positive impacts on the growth of GDP. This finding is supported by the anecdotal evidence, which suggests that Gambian youth are increasingly getting involved in the livestock and fish production, which in turn helps boost the economy of the Gambia. The world in general and the Gambia in particular, due to the unachievable nature of certain SDGs such as poverty (SDG no.1), hunger (SDG no 2), and climate change (SDG no.13), the world is still facing starvation, conflict, insufficient water supply and food production, malnutrition, and poor agricultural practices. According to Manap and Ismail (2019) wrote on Food Security and Economic Growth nexus confirmed that food security has an impact on economic growth, especially in dryland developing countries. Their study revealed that an increase in food security results in an increase in economic growth.

20.5.1 Limitations of the Study

This study has limitations that further researchers need to address. The first limitations go to the type of data used in this study, which was generally taking from the World Bank. Thus, the results might bring some important outcomes for food security if in the case household's survey is conducted on this topic such as households' characteristics, demographic status of the households, social and economic status of the households, production of food, and consumption of food by the households. This will have additional policy implications for the policy makers to implement possible solution to address the issues of climate change, food production, agriculture, and economic–growth nexus. The second limitation is that this chapter can use cross-section variation on food security to study different regions, countries, or continents that will yield sound results as well. Basically even more interesting results are built in this present study but using panel data model, especially fixed effects model will address some issues of specific error term in country or regions such as different in climate and weather, different in agriculture practice, different in political situation, different in institution and governance, and so on; all of these will have some outstanding results for the nexus between climate, food security, agriculture, and economic growth. The third limitations are the links between HDI index and agriculture productivity and food security that the study failed to addressed. The future researcher could add the specific country's Human development index (HDI) to see its relation with food security through agriculture-valued added. Finally, the last limitation can be based on this type of model. As the study addresses the dynamic model (ARDL) to see the trend of the variables in question. The results are actually very impressive, but it could also be nicer if some future research used instrumental variables, in order to select carefully the instruments so that the number of equations to be endogenous and number of equations to be exogenous to be exactly identifiable. This will help to select good proxy for the study.

20.6 Conclusion and Policy Implications and Areas for Future Research

This chapter tests the ARDL model and Granger causality linkage between climate change, growth in value-added agriculture, food production (food availability proxy), and economic growth, utilizing annual data from the period 1960 to 2017. The results empirically demonstrate the nexus that exists between food production, agriculture, climate change, and economic growth: (i) In both short-run and long-run, the ARDL model established that the growth of fish production and growth of livestock production in the Gambia have significant positive impacts on the growth of GDP. Thus, illustrating the importance of an increase in the production livestock and fishery on the economic growth of the Gambia. The possible policy implication is that it will affect the socio-economic interaction in the Gambia, such as employment of youth in these sectors, education for children from their guidance working on these sectors, the research for fishing and livestock, monitoring and control. (ii) In both short-run and long-run, ARDL model manifested that growth of food import and growth of agriculture have negative impacts on the growth of GDP. The possible policy implication is that the growth in food importation will increase government spending and budget deficit thus negatively impacting on government's ability to provide essential productive infrastructure and development. (iii) The Granger causality analysis between the growth of GDP and growth of food production indicates a unidirectional relationship, the direction of Granger causality may change according to the level of development. This illustrates that growth in GDP causes growth in food production or vice versa. (iv) Growth of GDP Granger causes growth of agriculture but growth of agriculture does not Granger cause growth of GDP, hence there exists an indirect relationship between growth in GDP and agriculture using Granger causality. (v) There exists a bidirectional relationship between the growth of crop production and growth of agriculture, thus manifesting that growth in crop production and growth in agriculture Granger cause each other. (v) It is worth noting that food production indicators (crop production, livestock production, and fish production), economic growth indicators (food import and food export and climate change indicator CO_2) for this study Granger causes agriculture. Finally, ARDL approaches and Granger causality tests manifested that the entire associated indicator has a degree of significance as captured in the methodology of the study. It is vital to note that there may exist on-linear relationship that cannot be taken into account by the ARDL approaches and Granger causality methodology even though that might be important to consider when analyzing the food production, climate change, and economic growth nexus. These nuances thus create avenues to possible future research. We hereby proffer the below-stated policy recommendations:

1. Gambian policy makers should devise a mechanism to increase the production of food and livestock to stimulate economic growth and development.
2. The Gambia needs to reduce its reliance on food importation by investing in food production to feed the rapidly growing population since food imports have a negative impact on GDP growth.
3. Provide the necessary infrastructure to expand agriculture (food, livestock, etc.) production to spur economic growth.
4. Streamline and simplify regulations in the agriculture sector to harness energy towards increasing productivity and growth.

Finally, the new directions of future research can add all the components of food security such as food availability, food accessibility, food stability, and food utilization to understand the effect of food production on economic growth in the Gambia in particular and the world in general. In additional, the future researchers should also look at the some of the variables closely such as CO2 emission per person, average precipitation, temperature, pollution or environmental quality, or industrialization level as a possible proxy of climate change. In a similar vein, the future researchers can also do a comparative study on climate change, food production, agriculture, and economic–growth nexus by looking at specific regions, countries, continents, West Africa, sub-Saharan Africa, and so on, to see the nexus between food security and economic growth.

Compliance with Ethical Standards

Ethical Approval
This chapter does not contain any studies with human participants or animals performed by any of the authors

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Not applicable.

Authors' Contributions
The authors worked jointly to come up with the chapter. Both authors read and approved the final manuscript.

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Not applicable.

Availability of Data
Dataset analyzed in this study is available from the corresponding author on reasonable request.

Conflict of Interest
The authors declare that they have no conflict of interest.

Appendix (Figs. 20.10, 20.11, 20.12, 20.13, and 20.14)

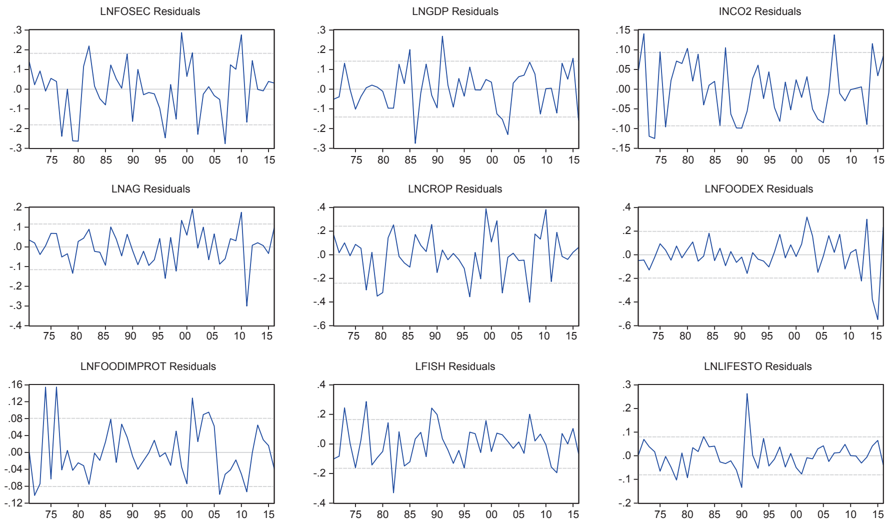

Fig. 20.10 Trajectory of residual of the variables used in the model using eview 10

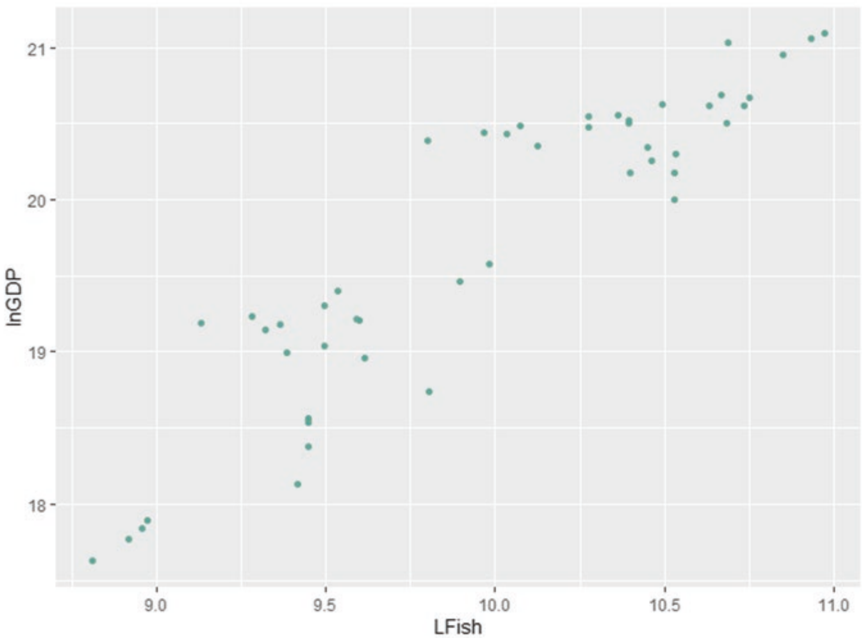

Fig. 20.11 Scatter plot for log of GDP versus log of fish production in the Gambia using Stata 16

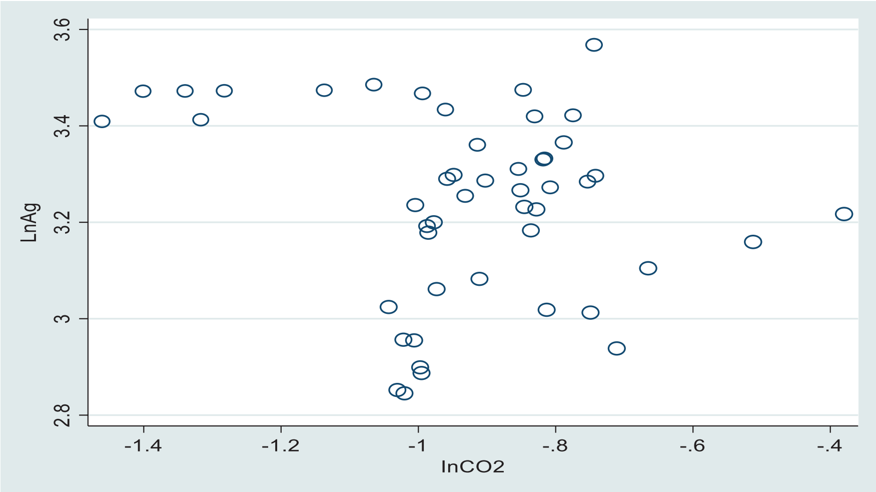

Fig. 20.12 Scatter plot for the log of agriculture valued added versus log of average precipitation and CO2 emission (Proxy for climate change) in the Gambia using Stata 16 foe window

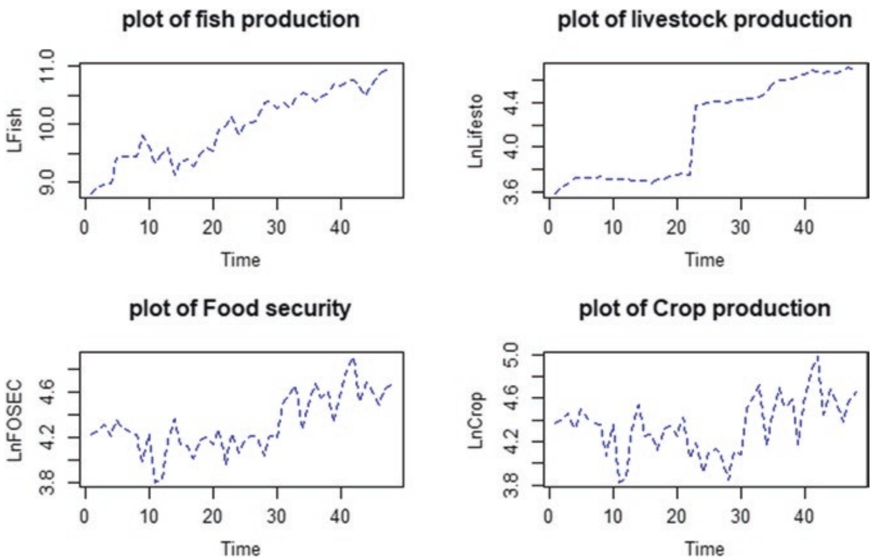

Fig. 20.13 Combination of graphs of growth of different variables used in the analysis by using R-studio

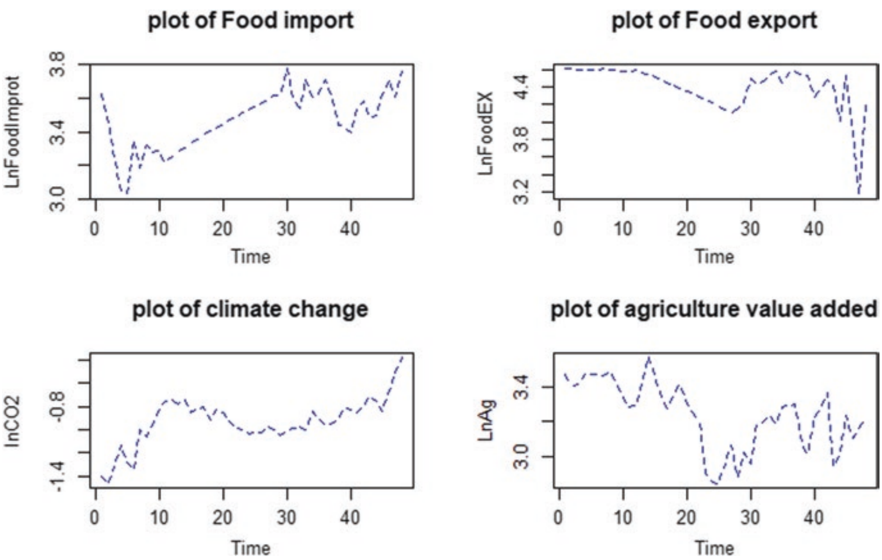

Fig. 20.14 Combination of graphs of growth of different variables used in the analysis by using R-studio

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Part IV
Animal Production for Improved Food Security

Chapter 21
Adoption of Genomics and Breeding Strategies to Improve Goat Productivity in Southern Africa

Phetogo I. Monau, Kethusegile Raphaka, and Shalaulani J. Nsoso

21.1 Introduction

Goats contribute considerably towards livelihoods, food and nutrition security as well as a pathway out of poverty in Africa. In the world, Africa is the second continent with the highest goat population of about 390 million (FAOSTAT 2014, http://www.fao.org/faostat), yet production is still low. Southern Africa has approximately 38 million goats (SADC 2014), and about 90% of goat population is kept under traditional management system characterised by small flock size, low-input extensive management and lack of modern management skills that are essential to improve goat productivity (Gwaze et al. 2009). The indigenous goat breeds are the most common breeds, yet they are haphazardly crossed with exotic breeds, which threaten their existence and relevance in the epoch of climate change. Other impediments include lack of appropriate policy and regulatory frameworks and weak policy implementation as well as poor recording systems (Molotsi et al. 2020). The use of genomic information however, through molecular technologies, gives insight on improvement of breeding strategies and ultimate goat productivity in the absence of records or pedigree information (Rupp et al. 2016).

A lot of efforts have been made worldwide to improve goat production and productivity through different technologies and evolving research systems. In Southern Africa, a few genetic improvements for goats were introduced but have mostly collapsed due to lack of comprehending the stakeholders' needs and existing production systems (Kosgey 2004). Despite the efforts to develop breeding programmes, the field of genomics has, however, not been adequately explored or exploited.

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Genomics has currently stimulated interest in molecular breeding where genotyping methodologies ensure genetic improvement and more accurate genetic evaluations of major or complex traits of economic importance (Marle-Koster et al. 2015). The use of genomics in Southern African goat populations will give clarity on breed composition, level of genetic diversity, identifying regions subjected to natural selection and specific mutations of interest and validate genealogical co-ancestry (Talenti et al. 2018). These aspects will ensure accurate genetic evaluations for breed effects, conservation and other breeding strategies on goat production in the region (Kristen et al. 2015). There are very few goats' genomic studies performed in the region and are mostly based on quantifying genetic diversity (Mdladla et al. 2016; Nandolo et al. 2019; Monau et al. 2020b). There is a need to use genomic tools and create synergies within the goat production value chain, including sustainable intensification and a sound structure aligned to the industries to improve food security. The aim of this chapter is to discuss possible perspectives on breeding and genomics to improve goat productivity in Southern Africa.

21.2 Feed and Feed Utilisation

Goat farming in Southern Africa is mainly practised on a small scale, partly due to scanty and irregular rainfall, financial constraints and shortage of feed. Goat nutrition is based on natural vegetation; hence, for the most part of the year it is limited in terms of quality and quantity (Monau et al. 2017). This, unfortunately makes it sensitive to droughts and climate change. The situation is exacerbated by insufficient water to enhance production of fodder through irrigation. The increase in human populations is likely to increase interaction between wildlife, livestock and humans with adverse consequences on grazing land and availability of water. The effects of climate change are likely to be felt in this part of the region due to poor mitigation and adoption strategies.

One of the possible mitigation strategies that could go a long way is to rear the indigenous goats because of their adaptation mechanisms to the prevailing adverse environmental conditions. To cope with drought, these goats have the ability to desiccate their faeces, to concentrate their urine, to reduce evaporative water loss and to utilise their rumen as a water reservoir (Silanikove and Koluman 2015). They have also developed better digestion efficiency which is attributed to maintenance of spacious rumen that allows longer retention time of feed particles, ultimately leading to reduced feed intake and small body weight (Silanikove 2000). The indigenous goats have proven to be feed efficient by eating less and maintaining the same production (Silanikove 2000; Salem and Smith 2008). One of the strategies to combat livestock protein demands is to use feed-efficient animals. Application of genomics can contribute to better understanding of the biological mechanisms underlying feed efficiency on indigenous goats and identify genes that can be used as biomarkers for feed efficiency traits in goats. In the long term, identification of such markers and using marker-assisted selection could enhance identification and breeding of more feed-efficient goats which can maintain the same production level with less feed. This will reduce feeding cost, support sustainability and improve food security.

21.3 Genetic Improvement Programmes

The genetic improvement of goats in the region can be described as breed substitution with exotic breeds, crossbreeding with highly exotic breeds and very minimal within-breed improvement. There appear to be tremendous impediments to genetic improvement within the goat production industry that are related to poor infrastructure, lack of goat management skills, poor recording and production systems, small flocks, low contemporary groups and a lack of relevant policies (Kosgey 2004).

A successful genetic improvement entails proper records of phenotypes and pedigree as an essential component of genetic evaluations. Information on phenotypic records assists in tracing gene flow from one generation to the next and measures influence on the expressed specific traits of interest (Molotsi et al. 2020). Namibia and South Africa are the only countries by far in the Southern African region that have embraced the recording system for goats, particularly commercial stud breeders. Apart from the abovementioned countries, other countries in the region could also learn from Ethiopia, where a study was carried out in the communal areas on Menz sheep and performance recording was done by the participating farmers and young boys taking care of the flock. The information on pedigree and live weights of Menz sheep breed could now be used in animal improvement programmes that will result in genetic gains for smallholder farmers (Gizaw et al. 2014). Each country should further develop a programme for recording relevant standardised phenotypes and pedigree to enable national genetic evaluation, optimum breeding schemes and genetic selection. New, improved recording technologies that have the potential to make recording simple, easy and cost effective for communal famers, for example, storing data on a centralised database using a cell phone, are available. This can be adopted for goat production in the region together with the open-nucleus system that has long been advocated for, to accelerate genetic progress.

Considering that most breeding programmes were curtailed by lack of structured selection process and uncontrolled and unsustainable breeding, the community-based breeding programme (CBBP) is a promising option to improve small-scale goat breeding programmes in Southern Africa (Monau et al. 2020a). CBBP considers the production system as well as the indigenous knowledge on breeding practices and breeding objectives. It also involves the local community at every stage from planning to operation of a breeding programme. This programme has been practised by smallholder farmers of Ethiopia since 2007 where it yielded positive results such as increased productivity, 3% reduction in inbreeding, increased chevon/mutton consumption, increased capital and sustainable utilisation of indigenous breeds (Gutu et al. 2015). CBBP can assist farmers to have clear market-oriented breeding objectives and adopt new technologies for sustainable production.

This will go a long way in making the goat industry a self-sustaining commercial activity for smallholder farmers. In addition, recorded data from the CBBP can be used for genomic strategies such as identifying candidate genes for traits of economic importance. A study using selected animals from the CBBP was performed towards identifying candidate genes for prolificacy on sheep (Marshall et al. 2019) and genes likely associated with trypanotolerance on red Masai and Dorper crosses (Berthier et al. 2016).

Despite the abovementioned challenges, it is still of importance to appreciate the locally adapted indigenous genetic resources and optimise their use. The indigenous goat breeds are the most popular and have the potential to be improved through within-breed selection programmes. These breeds possess a huge range of genetic diversity suitable for on-farm conservation, development of a plan for increased productivity, and genetic improvement and unforeseen environmental changes (Mueller et al. 2015). The available technologies on genomics can be used to facilitate rapid breed improvement of indigenous goats by applying gene-based selection for both productivity and adaptation (Rupp et al. 2016).

21.4 Genomics

The use of genomics includes whole genome sequencing, ribonucleic acid (RNA) sequencing and use of deoxyribonucleic acid (DNA) markers. There are several commercial DNA chips that have been developed to accelerate livestock genetic improvement including the goat gene chip. This chip contains thousands of single nucleotide polymorphisms (SNPs) and was developed by combining whole-genome sequencing and reduced representation libraries of eight goat breeds (Tosser-Klopp et al. 2014). Currently, this chip is the preferred vehicle for incorporating molecular information into a selection programme and developing genomic estimated breeding values (GEBVs) (Marshall et al. 2019). The chip has also been widely utilised in identifying casual variants (Henkel et al. 2019), parentage testing (Talenti et al. 2018) and genome-wide association studies (Islam et al. 2020; Scholtens et al. 2020), guiding conservation programmes and identifying adaptive traits of indigenous goats (Mdladla et al. 2016; Bertolini et al. 2018; Colli et al. 2018; Nandolo et al. 2019; Monau et al. 2020b).

Characterisation of indigenous goats remains imperative. Genetic characterisation of indigenous goats will open avenues for other genetic strategies such as genomic selection which has the potential to increase genetic progress and accuracy of selecting traits of economic importance (Rupp et al. 2016). Genomic selection enhances study of relationship among animals, increases accuracy of estimated breeding values (EBVs) and reveals functional variants of economic importance (Meuwissen et al. 2001). The use of genomics in the region will assist where pedigree information is lacking, which is always the case in traditional management systems. In such cases, genomic data can be used to build a genetic relationship matrix among animals in a new recording programme, so that EBVs can be spawned almost instantly (Marshall et al. 2019). The challenges that could be faced in using genomic technologies in the region is the cost of genotyping and less dense single nucleotide polymorphism (SNP) arrays which may lead to biasness and inability to identify rare alleles. Compared to the use of genomic information for cattle, the higher cost of genotyping, relative to the value of the animal, is still a strong economic barrier to uptake such a new technology in goat breeding. Consequently, most genomic studies performed in the region are small and underpowered to detect genetic variants that exist in indigenous goats. However, another approach to leverage in genomics is regional integration of data through collaborations to perform meta-analysis. Meta-analysis has the potential to improve the power to detect more associations, and to investigate the similarities or differences of these associations across diverse datasets and study populations (Zeggini and Ioannidis 2009). Furthermore, comprehensive research which includes cost–benefits analysis will be needed before the technology is rendered to stakeholders.

21.5 Goat Value Chain

Goat value chain is important for achieving sustainable competitiveness by efficiently producing products that are consumer recognised. In Southern Africa, the value chain has been constrained by a series of challenges. Current knowledge on clear breeding objectives, goat market structure, outlets, performance and price formulation are inadequate to inform policy and institutional reform (Gwaze et al. 2009). Existing opportunities in local, regional and international markets are largely unexploited. In Botswana, for instance, farmers used to sell goats at the national abattoir, Botswana Meat Commission (BMC); however, they stopped because of low prices and the delayed remuneration processes (Mrema and Rannobe 1996). Most goats had low grades at BMC due to long distances between farms and the market, poor feeding, internal parasites, etc. Farmers then opted to sell to private agents who offered better prices immediately on reaching the deal despite the market's unreliability.

In today's highly competitive and globalised world, the reliability of supply in terms of volumes, prices and quality on annual basis is key. Looking at the current situation, most countries in the region will keep on losing their market share to competitors. It is, therefore, important to comprehend market performances, conduct and functions, business linkages as well as constraints and opportunities along the value chain of goats. Change of mindset of smallholder farmers from subsistence thinking to commercialisation by linking production to market, relevant and reliable market information, proper infrastructure and formation of marketing groups could improve marketing efficacy and profitability of smallholder goat production system. This will assist on the business and policy decision-making in the goat industry, hence increasing the quantity and quality of offtakes and ultimately improving food security. The advancements in molecular technologies, genomic selection and proteomics will enable genetic improvement programmes that will focus on the ever-changing consumer demands. This could include the use of genome-wide association studies to identify genomic regions that underlie certain meat traits in indigenous goats. Such findings will facilitate determination of marketing points for indigenous goats and going as far as identification of niche markets for their product.

21.6 Outlook for the Future

21.6.1 SWOT Analysis

It is important to highlight the strengths, weaknesses, opportunities and threats of the goat industry in Southern Africa as a way forward. The strengths of goat production obviously lie with its multifaceted characteristics such as high nutritional quality derived from goat products, high resilience of the indigenous goat to different production environments, contribution of goats to the ecosystem and intangible cultural legacy. The weakness of goat production involves the low productivity of indigenous goats and chances of losing them, low adoption of technologies, harsh rearing conditions, lack of cooperatives preventing commercial development and scarce representation of the sector in the decision-making bodies. There are several opportunities that can be explored in the goat industries: the increased demand of goat meat regionally and internationally, tourism activities and indigenous goat products that could pertain highly to niche markets, other goat products including milk production and processing it into high-value products, for example, goat cheese, shampoo and soap. The other opportunities include new technologies that can be applied to the livestock sector and making management and goat farming more attractive to young people. The threats include competition with other industries such as crop production, tourism, mining and cattle and poultry industries. The industry is exposed to climate change, which affects the productivity of the flocks and the quality of the product. There is limited high-end research on indigenous goats hence insufficient progress in improving the sustainability of the sector, most researchers turn to other species, which are cheaper and guarantee easier and faster career development.

21.6.2 Scientific Research

Sustainable and efficient research is the key to drive goat production in the region. Research goals should be strategically aligned to provide answers to the actual needs of goat farmers and consumers. There should be participatory research with key stakeholders and development towards hurdles in feeding, breeding and general management of goats. Considering that indigenous goat breed has evolved over time and has developed unique adaptive traits suitable for current and future environmental and socio-economic endeavours provides opportunities for breed development and exploitation. Survival of these goats depends upon their continued use in traditional production environment where their hardiness and efficiency have economic value. It is important to invest in the indigenous breed and promote it for climate change and food security. For instance, if the primary goat product is meat, a well-designed breeding programme may improve meat production of indigenous goat while maintaining their secondary traits such as adaptation to the environment. This can be done gradually without increasing energy demands that cannot be met by the available grasslands. In addition, genetic characterisation of indigenous goats in the region should be done holistically and compared with other breeds in terms of production, resilience to environmental hazards and reproduction. Information on unique adaptive traits and genetic diversity can be exploited in selection for increasing production and contributing to food security.

21.7 Conclusions

The existing production system and economic structure of goats in the region has not changed over the years. Goats still play an integral part of subsistence and diversified commercial farming, and almost every farmer keeps a few goats. Strengthening of the existing infrastructure along with technical input and strategic improvement of extension delivery is essential for achieving increased goat productivity and market orientation of smallholder producers. It is important to evaluate the indigenous goat breeds through structural breeding programmes and promote them for climate change and food security. The use of genomics can assist to accelerate genetic improvement, evaluate breed effect, and monitor and control inbreeding of goats in the region. The sector should have dominating corporations that are vertically integrated, controlling every step from selection of breeding stock to marketing. This will assist in commercialisation, adoption of technologies and general management of goat productivity.

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