Arvind Kumar ·
Pavan Kumar · S. S. Singh ·
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Meenu Rani *Editors*

Agriculture, Livestock Production and Aquaculture

Advances for Smallholder Farming Systems Volume 1

Springer

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Advances for Smallholder Farming Systems
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ISBN 978-3-030-93257-2 ISBN 978-3-030-93258-9 (eBook)
https://doi.org/10.1007/978-3-030-93258-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Agriculture is an important sector of the Asian economy as more than half of its population relies on farming as the principal source of livelihood. Agriculture not only contributes to overall economic growth but also reduces poverty by providing employment opportunities and food security to the vast population in this continent, providing inclusive growth. During the last half century, agricultural research and extension has mainly focused on enhancing productivity by developing improved crop varieties, increased fertilizer use, elite animal breeds, efficient farm implementations, and location-specific up scaling of production technologies.

This book, entitled ***Agriculture, Livestock Production and Aquaculture: Advances for Smallholder Farming Systems***, presents the technological interventions in agriculture, livestock, and fishery in the twenty-first century including the primary agricultural dynamics, livestock and fishery resource management, mitigation strategies for sustainable food security systems, and climate-smart solutions to improve soil health and farm productivity. In view of the vulnerability in agricultural systems, I believe that this book not only serves as a guide for the scientists and various other stakeholders engaged in agriculture and applied sciences but is also a key resource for the scientific research community, emerging professionals including industrial sector, and developmental agencies for advancing the cause of agricultural sector.

I congratulate the editors of the book including Arvind Kumar, Pavan Kumar, S. S. Singh, Bambang Hendro Trisasongko, and Meenu Rani, the national and international contributors, as well as the publisher for bringing out this timely publication depicting opportunities in agriculture, livestock production, and aquaculture for smallholder farming systems. I hope that this important book shall serve as a reference for different institutions working in this area.

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Preface

Food security is one of the major global challenges. Countries have paid more attention to food availability, taking into account uncertainties resulting from hazards (including climate change), mismanagement, economy, and policies. Shifting climate patterns observed in many parts of the world encourage further adaptation and research on numerous agricultural aspects. These include additional crop management like irrigation, selecting cultivars adapted to new challenges, and implementation of technologies to monitor the dynamics in agricultural fields. After the COVID-19 pandemic, securing countrywide food supply became a priority for countries, leading to limiting food trade at the regional and global level.

In many parts of the world, small-scale farming has been the primary issue to improve the outcome of the agricultural sectors. Complexity is evident in fragmented agricultural lands, in the aspects of food production, their resilience to hazards, and fields management. In this book, Kumar provides an excellent introduction to this issue and provides details on the influence of climate on agriculture as a whole and the policy implications.

Soil is a key resource in agricultural systems. Vital indicators for healthy soils such as soil organic carbon have been the primary focus of research and the implementation of the results. This book overviews current knowledge by focusing on nitrogen as one of crucial elements in plant growth. Ntinyari studied nitrogen losses in Africa, which not only allow saving of funds but are also important in minimizing nitrogen's detrimental effects on nature. Since groundnut is also important to Africa, Sakha evaluated value chain for food production. Related to this is aluminum stress, which is discussed by RS Dubey, and salinity and debate about manpower, which is the central concern in agriculture in developing countries, deserve attention. Current issue related to gender is discussed by Sah. Kumar explored the harvest agricultural production portrayal and evaluation for agriculture's sustainable development and a perspective view of nitrogen in soil, plant, and water.

Monitoring crop production on a wide scale is a distinctive challenge. This role is discussed in Part II. Resilience for salt tolerance in rice cultivars using various strategies of conventional molecular breeding was evaluated by Singh. Land suitability is an important step to achieve optimum yield based on the available land resources, as discussed by Hilda. Information retrieval is shown to be crucial for agricultural planning; hence, methods to derive information need to be well understood. While the aforementioned chapters debate on the food production aspect, agriculture is well known to be vulnerable to numerous hazards. Shofiyati presents a remote sensing scheme to assist stakeholders in further protecting smallholders through agricultural insurance.

Agriculture, as a whole, interconnects different parts, including animal husbandry and aquaculture. Crop production can either directly or indirectly be associated with aspects in livestock management. To extend the debate, Chatterjee addresses poultry resources and their importance in food security while emphasizing the crucial role of rural areas. Das further explores using pigs as a focal issue to highlight the importance of securing regional food supply. Lopamudra Haldar explains food safety and product quality, using milk as an example. The importance of this technology is accompanied by further development, as this issue remains unresolved depending on the scale of livestock production.

Part V documents the contributions of fisheries in food security. SK Das initially presents a contribution to this issue, specifically discussing about smallholder farmers. Since diversity of knowledge and skills among farmers is considerably high, a study is required to further understand this variety. The introduction of technologies suitable for ecologically sound aquaculture management to the stakeholders is important to improve farmers' livelihood, while maintaining their surrounding environment. Ratan Sen explains strategies for added values, particularly in terms of meat and fish goods. India is the second-largest fish producer in the world. Kumari considers the observations from the open literature about the metal (loid) concentrations in Indian freshwater and marine fish species.

Luc Hens Keerbergen, Belgium

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About the Editors

Arvind Kumar, a renowned educationist and researcher having more than four decades of experience, has been given the responsibility as first Vice-Chancellor, since May 2014, by the President of India to develop the campus and academic program of Rani Lakshmi Bai Central Agricultural University, Jhansi, an Institution of National Importance. Prior to this assignment, Prof. Kumar worked as Deputy Director General (Education), ICAR, New Delhi from 2009 to 2014; held the additional charge of Deputy Director General (Fisheries), ICAR, New Delhi, for about 5 months; and was the Director of the Directorate of Rapeseed-Mustard Research (DRMR), Bharatpur from 2002 to 2009. He is a fellow of the National Academy of Agricultural Sciences (NAAS) (2012) and a fellow of the International Society of Noni Science (2018). He has been also the President of ISOS, ISA, and SRMR. Prof. Kumar received the Lifetime Achievement Award for his significant contributions to agronomy and rapeseed mustard from the Indian Society of Agronomy and Society for Rapeseed-Mustard Research. He has been a member of the Board of Management of several nationally reputed institutions like IARI; GBPUA&T; CAU, Imphal; SKUAS&T, Jammu; and NDRI, Karnal. During his professional career at GBPUA&T, Pantnagar, for about 27 years, he was involved in teaching, research, and extension education and was also assigned various responsibilities, including Joint Director Extension. For his outstanding contributions to the field of rapeseed-mustard research, he was given “Membership” by the International Consultative Group for Research on Rapeseed, Paris (France) from India. Prof. Kumar has been honored for his professional achievements with several awards and fellowships. He has published more than 160 research papers in Indian and foreign journals, 90 popular articles, 60 books/booklets/chapters, and presented more than 200 papers in national and international conferences on aspects of oilseed research and management. He has visited 24 countries for professional reasons and holds a vast National and International experience.

Pavan Kumar is an Assistant Professor (Wildlife Biology) in the Department of Forest Biology and Tree Improvement, College of Horticulture and Forestry, Rani Lakshmi Bai Central Agricultural University, Jhansi, U.P., India. He obtained his Ph.D. degrees from the Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi. He did B.Sc. (Botany) and M.Sc. (Environmental Science) from Banaras Hindu University, Varanasi, India, and subsequently obtained a Master's Degree in Remote Sensing (M.Tech.) from Birla Institute of Technology, Mesra Ranchi, India. His current research interests include forest, resilient agriculture and climate change studies. He is recipient of Innovation China National Academy Award for Remote Sensing. Dr. Kumar has published more than 60 research papers in international journals as well as authored several books and presented more than 40 papers in national and international conferences. He has visited countries like the USA, France, the Netherlands, Italy, China, Indonesia, Brazil, and Malaysia for various academic/scientific assignments, workshops, and conferences. Dr. Kumar is member of the International Associations for Vegetation Science, USA, and the Institution of Geospatial and Remote Sensing, Malaysia.

S. S. Singh is Director of Extension Education, Rani Laxmi Bai Central Agricultural University, Jhansi U.P. He has served as director of ICAR-Agricultural Technology Application Research Institute, Kolkata (2017–2020). Dr. Singh has handled 16 foreign/externally funded projects on natural resource management, crop management, livelihood development, and crop improvement funded by DFID, IFAD, USAID, BMGF, IRRI, CIMMYT, Ford Foundation, and European Union. As an agronomist, he has contributed to the development of five rice varieties which have been released by CVRC and Bihar SVRC and are suitable for aerobic drought prone, late direct seeding, contingency cropping, and rainfed lowland conditions. He has published 115 research papers, 6 books, 20 book chapters, 15 technical bulletins, 135 papers in proceedings/ symposiums/seminars, 50 popular articles, and 40 extension folders. He has visited the USA, the UK, Australia, Mexico, Thailand, Philippines, Bangladesh, and Nepal. He is recipient of Rajeev Gandhi Gyan Vigyan Award from the Ministry of Home Affairs, FAI award, Senior Research Fellowship of ICAR, and Excellent Team Research Award of ICAR in Social Science.

Bambang Hendro Trisasongko is an Assistant Professor in the Department of Soil Science and Land Resources, and a member of the Geospatial Information and Technologies for the Intelligent and Integrative Agriculture (GITIIA) research program at Bogor Agricultural University, Bogor, Indonesia. Dr. Trisasongko has 14 years of research teaching experience with a publication record in research articles, review papers, conference papers, and book chapters. Dr. Trisasongko is reviewing research articles for a number of scientific journals and has handled research projects in his capacity as PI and Co Pi. His research areas have been in remote sensing for agriculture, environment and forestry. His current research focus in plant productivity from remote sensing and proximal sensors.

Meenu Rani is a Researcher in the Department of Geography, Kumaun University, Nainital, Uttarakhand, India. Dr. Rani received her M.Tech. degree in remote sensing from Birla Institute of Technology, Ranchi, India. She got working experience in the major disciplines of agriculture and forestry while working with Haryana Space Application Centre, Indian Council of Agricultural Research, and GB Pant National Institute of Himalayan Environment and Sustainable Development. Dr. Rani has authored several peer-reviewed scientific research papers and presented works at many national and international conferences in the USA, Italy, and China. She has been awarded with various fellowships from the International Association for Ecology, Future Earth Coast, and SCAR Scientific Research Programme. She received an early career scientists' achievement award in 2017 from Columbia University, New York, USA.

Part I
Current Approaches to Sustainable Agriculture in Smallholder Farming System

Chapter 1
Impact of Future Climate Change on Agriculture, Livestock Production and Aquaculture: Challenges and Policy

Arvind Kumar and Pavan Kumar

Abstract Agriculture around the world is vulnerable to climate change. Therefore, adaptation measures are required to sustain agricultural productivity, reduce vulnerability, and enhance the resilience of the agricultural system to climate change. Agriculture is an important sector of the India's economy and plays a significant contribution. Indian economy contributed around ~17.4% to the country's Gross Value Added for 2019–2020. Of the total population, 54.6% is involved in agriculture and allied activities. Agriculture is an important sector in India, which is the major source of the food and livelihood security of the vast population. Uttar Pradesh (UP), the largest wheat producing state can witness a major yield loss due to climate variability and extreme weather events. The research is purely based upon the analysis of climate parameters and its impact on agricultural production in present and future scenario. It does not consider non-climatic factors such as land use, technological enhancements, and change in irrigation pattern, soil fertility, and crop damage due to insects and pests' attack. The research also helps the decision and policymakers to prioritise the vulnerable zones that need immediate attention. Therefore, the research design must incorporate the present and future risk and proper implementation should be monitored.

Keywords Agriculture · Aquaculture · Climate change · India · Livestock · Policy

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_1

1 Impact of Climate Change

Climate change impact is well known worldwide, and it is the biggest challenge facing the global society at present and it has become a great necessity at the present time. Statistics show that the average temperature of the Earth's surface has increased by about 1.62 °F since the late nineteenth century (Boer et al. 2000; Damtoft et al. 2008; Roberts 2008). Apart from this, sea level has also increased by about 8 inches since the last century (Rohde et al. 2013; Boisier et al. 2012; Knox et al. 2016; Hansen 2007). Global climate change comprising changing surface solar radiation, accelerated warming temperature, variable precipitation and increasing CO_2 concentration is projected to have a significant influence on crop production and their development (Bale et al. 2002; Adger et al. 2003; Laseter et al. 2012; Asseng et al. 2011). It affects agriculture in various ways, including through temperatures, heat waves, changes in sea level, average rainfall, atmospheric CO_2, and ground-level ozone concentrations. Due to the insufficient regular record of climate data such as temperature, daily radiation, precipitation, etc., on the future circumstances, it is hard to conclusively establish site-specific impact assessments of future climate variation on crop productivity (Huq et al. 2004; Daly 2006; Tao and Zhang 2013; Zhang et al. 2017). The impact of drastic changes in climatic conditions is an important scenario (Stevens and Madani 2016; Tao et al. 2013; Yang et al. 2018; Liu et al. 2017). The IPCC (2001) announced that the increase in the recorded Earth's temperature during the last 50 years is the result of various human activities (Tao et al. 2016; Trenberth 2001). The governments across the world have responded to the threats associated with climate change.

At one time all climate change was natural. Mechanical conflict came around 220 years back because of which tremendous amounts of products were produced by machines. Energy is required to run the machines (Womack et al. 1990; Gutowski et al. 2006). During the last 200 years, due to our activities, huge quantities of greenhouse winds have been emitted in the atmosphere. It is now clear that in today's time, humans are responsible for climate change (Amiri and Eslamian 2010; Weber and Stern 2011). Earth is the only planet on which life is possible. The presence of favourable temperature on the surface of the Earth is an important factor in the presence of life; the average surface temperature of the Earth is 14.4 °C. Climate change is a very slow change process but at present the rate of changes is very fast and because of these changes the earth is warming rapidly. Due to global warming, temperature is increasing, and many parts of the country are witnessing changes in climate change such as rain, temperature, weather, etc. (Kovats et al. 2001; Davis and Shaw 2001; Wilcke et al. 2013).

2 Climate Change: Global status

The year 2020 was a challenging year and such years are rarely seen. This year the entire planet came to a standstill. The incidence of the COVID-19 taking the form of a global pandemic remained at the centre of the world; however, last year the world saw many important events from the point of view of climate change. The year 2020 was the second hottest year. Greenhouse gases (GHGs) were released into the atmosphere at a record level and due to this the surface temperature increased significantly. Climate-related seasonal disasters, especially hurricanes and forest fires, were seen to be more frequent. This year was also very unstable and turbulent in terms of geopolitics all over the world. Finding solutions to the problems arising from climate change in many developed and developing countries of the world is on-going – but India's problem was not only climatic, it has its own speciality due to a number of reasons (IPCC 2007). There has been an increased awareness of the challenge of climate change and its adverse effects (Sathaye 2007). India is an agricultural country. The effect of climate change is falling on the economy of our country. Due to insufficient amount of rain, its direct effect is on the air temperature (Bacci et al. 2016).

3 Climate Change Impacts in South Asia and India

India will be the worst impacted by the increasing global warming due to the rising levels of GHGs. High temperature during wheat gain filling is being increasingly experienced, resulting in 4–5% yield losses. Even 2 °C temperature rise could permanently reduce the gross domestic product (GDP) by 4–5% for India (Stern 2006). In the past decade, South Asia's environmental disasters have increased and caused significant damage to people (Singh et al. 2014; Tesfaye et al. 2017). Flooding is not uncommon in Pakistan, but when floods affected one-fifth of the country in 2010, it became clear that climate change was on a much larger scale. South Asian zones might encounter a warming impact of 2–6 °C during the twenty-first century (Ravindranath and Ostwald, 2007). In particular, Indian sub-mainland and different landmasses are profoundly helpless against a wide range of existing environmental change issues. Unlike many developed countries, people in South Asia are vulnerable to environmental problems due to lack of industrialisation and high dependence on agriculture. When the economy of a state weakens because of external, environmental factors, the country's security is also negatively impacted. Mani et al. (2018), economic experts on South Asia affairs of the World Bank, examine the impacts of temperature and precipitation changes on living standards. The temperature in India drastically increases day by day (Fig. 1.1) and will increase by 1–2 °C annually until the year 2050 due to climate change. This will result in a decline in the standard of living of nearly half of India's population, including farmers, workers and small businessmen, with an impact on agriculture, the labour sector and small industries (Fig. 1.2).

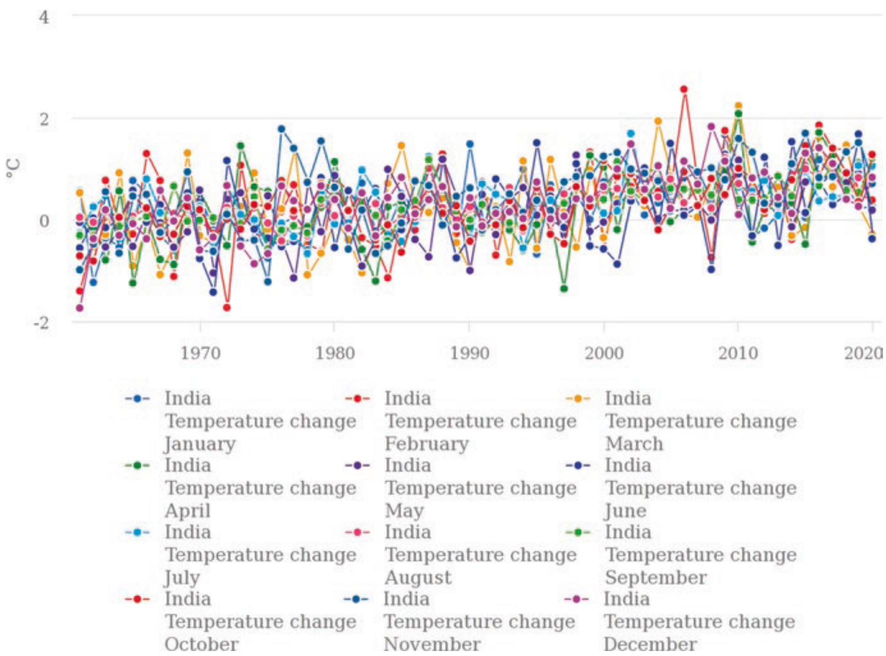

Fig. 1.1 India's temperature change (1960–2020)

3.1 Floods

Millions of people had to live in cover houses in Bihar because of floods in 2008. According to climate scientists, the main reason for these floods is the rise in sea temperature (Tripathi 2015). Similar catastrophic floods have occurred in Indian-administered Kashmir in 2014, in Uttarakhand in 2013 and in many parts of India in 2015. Around 20 million individuals dealt with the comparable issue in Mumbai in 2005.

3.2 Droughts

Arid regions in South Asia, including dry regions of Rajasthan in India and few areas of Pakistan, are confronting extreme dry season. Crop failure and drought have become a permanent problem over the years. Drought conditions have persisted in India for a long time but these days it has increased in frequency and intensity (Sahana et al. 2020). Western Rajasthan, Southern Gujarat, Madhya Pradesh, Andhra Pradesh, Maharashtra, Southern Bihar, Northern parts of Haryana, Uttar Pradesh and Karnataka are consistently confronting dryness, and these districts are profoundly helpless against dry season (Bhadwal et al. 2019). The arid and semi-arid zones are susceptible to the livelihoods and losses of economic activities due to the changes in precipitation rate.

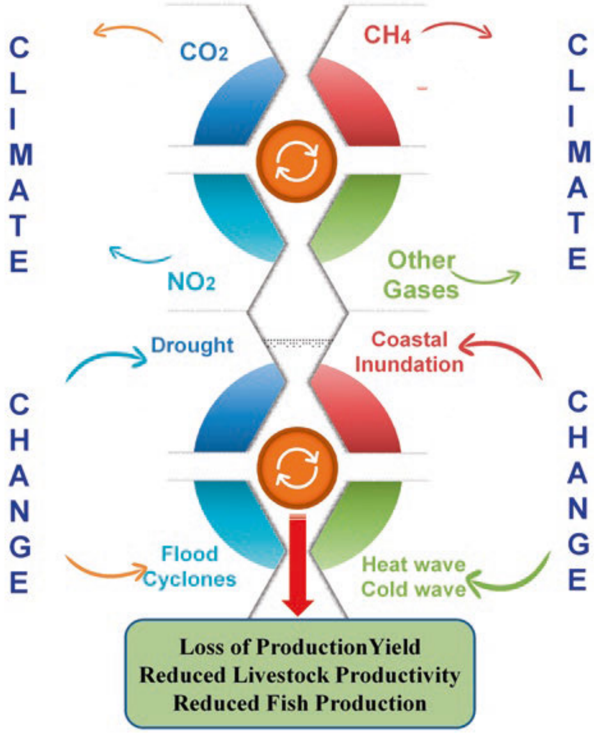

Fig. 1.2 Causes and effect of environmental change on agriculture and allied sectors

3.3 Biotic Stresses, Biosafety and Biosecurity

The number of invasive species and exotic pests has been rising. The threat from new pathotypes, such as the rust races of wheat, has increased (Sharma 2017). The incidence of bird flu and swine fever is also rising, let alone the animal health problems cause due to trans-boundary animal diseases which are causing enormous losses. A holistic approach to comprehensive national biosecurity umbrella is missing the adversely impacting trade and food security.

3.4 Post-Harvest Losses, Value Addition and Value Chain Management

Indian agriculture suffers heavily from post-harvest losses, averaging 15–25%, being particularly high in horticulture, livestock and fisheries. Due to poor and inadequate grain storage facilities the food grains procured for the Public Distribution System (PDS) as well as for buffer stocking suffer severe losses both in quality and quantity. This problem will become acute with the enactment of the food bill.

3.5 Secondary Agriculture, Renewable Energy, Smallholder and Marginal Farmers

The rich indigenous biodiversity is underexploited for producing world class herbal products. The huge biomass produced every year in the country is fully utilised and is hardly used for producing bioenergy and biofuels. Nearly 85% of the farming families are smallholder including small, marginal and sub-marginal. Nearly 80% of these are marginal (<1.0 to 0.5 ha) and some marginal (<0.5 ha) and the number is increasing. Despite their higher per unit productivity, the extremely small and fragmented holdings are becoming economically non-viable and the sub-marginal as well as marginal farmers are swelling the ranks of the hunger and poor.

4 Climate Change Impact on Indian Agriculture

India ranks second globally in agricultural and food production. Areas of the world that are currently producing rice, wheat and grains may be unable to produce that much because of global warming (Knox et al. 2016; Wheeler 2011; Wang et al. 2016). This will also affect the availability of simulations. Increased evaporation and dryness of soil in some areas will lead to prolonged drought-like conditions. The need for irrigation in arid areas will also increase. In hot areas, due to pest and disease of crops and weed growing, agriculture will be infested (Rockström 2003). In such a situation, the World Bank has studied the economic aspect of climate change, according to which due to uncontrolled climate change, India's GDP can be affected by 2.8% and by 2050 about half of the population will be affected (Lizumi et al. 2017; Baker 2012).

Soil, like other components of agriculture, is also affected by climate. The soil was already becoming organic carbon-free because of chemical fertilisers; now increasing the temperature is affecting the moisture and workability of the soil and increasing the salinity in the soil. Declining groundwater level is affecting soil fertility. Soil itself is a natural ecosystem where the components of the food chain, i.e. producer, consumer and dissection, all three processes go on continuously (Aggarwal 2003; Aggarwal et al. 2004; Aggarwal and Sinha 1993; Gadgil et al. 1999; Lal et al. 2001). If the current rate of temperature rise continues, obviously soil temperature will also increase in the future (Fig. 1.2). Plants obtain their food by mineralisation of organic matter and micro-biological processes. Due to the increase in biological activity of micro-organisms by increasing the soil temperature, the maximum dissolution of organic matter, organic carbon and nitrogen will emit more amounts of nitrous oxides and carbon dioxide gases (Lal et al. 1995; Hamlet et al. 2007; Huenneke et al. 1990; Mall et al. 2004). On the other hand, for the supply of micro-organism organic energy, there will be a decline in the amount of maximum organic and nitrogen organic matter, which can have far-reaching consequences in terms of soil fertility and productivity. As a result, the use of organic materials in crops is reduced and the total soil bio-carbon and nitrogen sources are reduced, that is, the plants will be unable to use them (Zreda and Desilets 2005; Schaefer et al. 2007; Lobell et al. 2002; Dai et al. 2004). Apart from this, their contribution can be in the form of increase in the effect of plant gases and increase in global temperature. The accumulation of salts on the upper surface of the soil by excessive evaporation can reduce the availability of minerals, water and other nutrients from the land, which may have a direct impact on the production of crops due to a decrease in soil productivity (Schlesinger 1990; Melillo et al. 2002).

Global evapotranspiration increased at a rate of about 7 millimetres per year each decade between 1982 and the late 1990s. However, it appears that this significant growth stopped in 1998. Due to the transfer of climatic zones through climate change, the order of crops can change naturally. There are several crop simulation models now accessible for the same crop that can be utilised for impact assessment of future climate change. Crop climate models incorporate current information from different disciplines including soil material science, agro meteorology, soil science, plant reproducing, crop physiology, and agronomy into a lot of mathematical equations to predict crop yield. Global Climate Models (GCMs) can be utilised to extend future climatic conditions (Moss et al. 2010). Different crop models can also be utilised to reproduce crop growth developments and yields (Taylor et al. 2012). GCMs yield information cannot be directly utilised in site-explicit impacts of climate change on crops due to coarse and temporal resolutions of GCMs output (He et al. 2017). The objective of this research an endeavour was made to utilise climate change scenario from the GCMs output as input for the process-based crop models used to evaluate the effect of future climate change on wheat production (Fig. 1.3).

5 The Changing Socio-Economic Environment

The main socio-economic factors that drive increasing food demand are population growth, increasing urbanisation and rising incomes. As regards the first two, population growth and urbanisation, there is little uncertainty about the magnitude, nature and regional pattern of their future development. Despite urbanisation, rural populations will grow faster than employment in primary agriculture, which is typically the case in transforming countries, so governments must facilitate the gradual transition to non-agricultural employment. This will require an institutional environment in rural areas that is conducive to multiple sources of employment and income generation. In Asia and Latin America, a large proportion of the rural labour force is already working full or part-time in non-agricultural jobs. In the agriculture-based countries of sub-Saharan Africa, these shares are still much lower, especially for women. The greater part of the rural labour force is still employed in agriculture and depends on productivity growth within smallholder agriculture to improve their incomes and food security (Fig. 1.4). However, as the rural population pressure is increasing, governments will have to address the rural employment transition here as well.

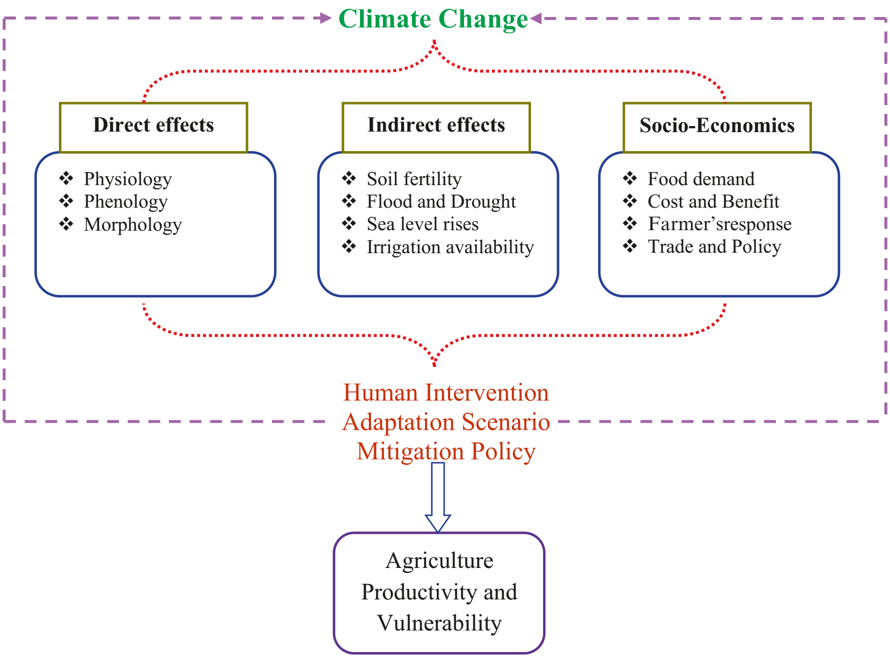

Fig. 1.3 Consideration of susceptibility of agriculture to climate change

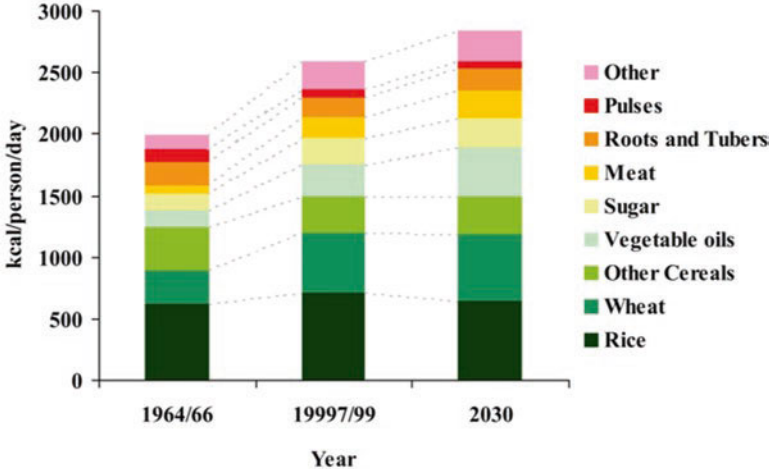

Fig. 1.4 Global progress in food consumption

6 Indian Agriculture – Past, Present and Future

Indian agriculture production system represents a success story that has no parallel in the world. From a country labelled as 'Begging Bowl' is today a food exporter coupled with an overproduction associated problems in many commodities. Over 200 years ago, 90% of the population depended on agriculture for a living. The technology was not very developed then so they used traditional methods of farming (Singh 2019). Today farmers are able to use technologies which allow them to produce more yields in less time. Looking back at the past 70 years or so it may be worthwhile to feel proud that today the nation has reached a level where National Food Security Act is now in place and no one in the country needs to go to bed hungry as they have a legal right to food. The history of Indian agriculture can be described in three phases. The first phase (pre-1960s) consisted of subsistence agriculture where Indian farmers were cultivating traditional varieties. In second phase, the humiliations that India had to face for importing grains to feed its population, inspired the politicians and scientists to find a quick solution to this embarrassing situation. This phase lasted up to 1990, and the emphasis during this period was on maximum production with high yielding varieties, use of chemical fertilisers, plant protection measures and irrigation. The third phase began in the 1990s with the realisation that problems are cropping up which were not envisaged earlier. The causes were obvious because the focus on enhancing productions only resulted in the degradation of natural resources and the partial factor productivity kept on decline continuously. Green Revolution Sustainability became buzzwords, and many strategies were put forth to make this a reality including bringing green revolution to Eastern India. The Green Revolution solved the problem of insufficient food production but even today we have about 200 million peoples below the poverty line. Their inability to buy enough food will not be mitigated just by increased production. The question today is not of food grain production, but of food grains consumption; many experts predict that our food requirements will exceed production in the decades to come. The value of gross production has been compiled by multiplying gross production. Thus, the value of production measures production in monetary terms at the farm gate level. The value of gross production (Fig. 1.5) is provided in both current and constant terms and is expressed in US dollars and Standard Local Currency (SLC). Food production, export and import quantity are examined in Fig. 1.6. http://www.fao.org/faostat/en/#compare.

7 Policy and Institutional Issues

7.1 Investment in Agricultural Research

The investment intensity in agricultural research at 0.6% of agricultural GDP is much lower than the overall average for all developed countries (1.5%). Further, there is considerable inter-state variability in the intensity of state funding ranging from 0.1% Uttar Pradesh to 1.5% in Himachal Pradesh. State Agricultural

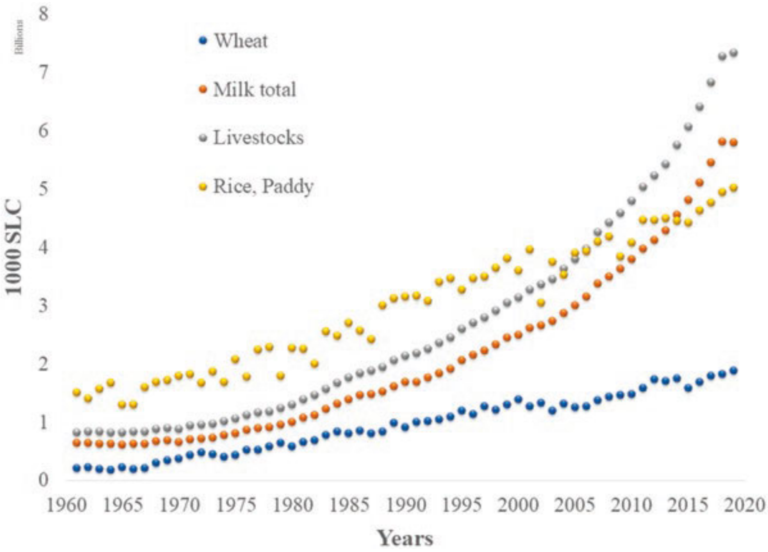

Fig. 1.5 India's gross production value (current thousand SLC)

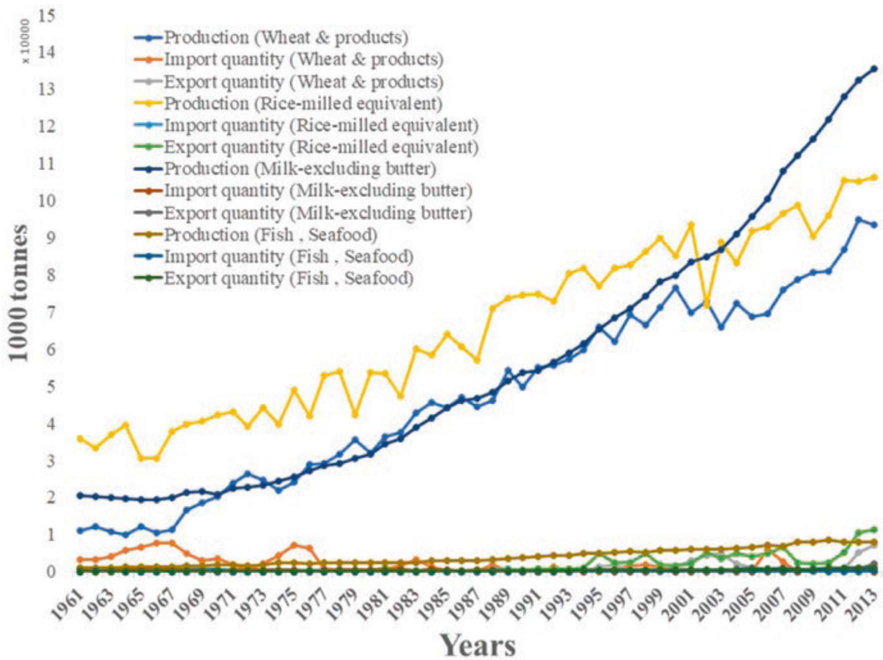

Fig. 1.6 India's production, export and import quantity

Universities (SAUs), the main seats of the agricultural research in the states are starved of funds, especially operational fund. In agriculture as a whole, the investment had declined and stagnated in the 1980s and 1990s leading to a slowdown in the agricultural growth or even decline in the Total Factor Productivity (TFT) growth.

7.2 Human Resources

There is a general deterioration both in quality and quantity of the human resources. A very large proportion of teaching faculty scientist position in the Institute as well as in the state agricultural universities is lying unfilled. The Land Grant College system of integrated research, education and extension is eroding fast. Despite the increasing demand for a robust knowledge society and increasing knowledge-based competitiveness, the academy standards are falling. Financially, most SAUs are in the pitiable condition. Paradoxically, there is a race for splitting and multiplying SAUs, destroying the integrated character and multi-disciplinary enrichment of the sector, let alone the serious financial implications.

7.3 Gender Dimension

Women comprise one-third of the entire workforce in the country, but three-fourth of the economically active women are engaged in agriculture. Limited research has been done to empower women technologically and knowledge-wise to enhance their agricultural efficiency and income, let alone their restricted entitlement to agricultural land, limited access to credit and extension services and exclusion from decision-making process and community-based development schemes.

7.4 Collaboration and Coordination at National and International Level

Avoidable duplication Policy and institutional issuesnational and international collaboration and coordination in a research efforts-investment, institutions and programmes are common. Effective mechanisms to ensure convergence a man concerned Ministries, Department, The Indian Council of Agricultural Research (ICAR), universities and SAUs are the exceptions. Bilateral international programmes are still mostly donor driven. The National Agricultural Research Systems (NARS) should be able to influence the activities of the Consultative Group on International Agricultural Research (CGIAR) centre undertaken in the country. Independent in-depth evaluation and review of externally funded research programme is seldom done. The impact of international collaboration in technology generation technology sharing and training should be assessed and rendered more effective.

8 Conclusion

The research is purely based upon the analysis of climate parameters and its impact on agricultural production in present and future scenario. It does not consider non-climatic factors such as land use, technological enhancements, change in irrigation pattern, soil fertility, and crop destruction due to insects and pests' attack. Despite this, the research provides important valuable information to different people in different fields. Further, the study helps the decision and policymakers to prioritise the vulnerable zones that need immediate attention. The study also helps to know the risk area which can become highly vulnerable zone in the future. Therefore, the study design must incorporate the present and future risk and proper implementation should be monitored.

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Part II
Adaptation and Mitigation Strategies in Smallholder Agricultural System Under Climate Change Scenario

Chapter 2
Managing Agricultural Nitrogen Losses in Crop Production and Mitigation of Climate Change Effects

Winnie Ntinyari, Mekonnen Giweta, James Mutegi, Cargele Masso, and Joseph P. Gweyi-Onyango

Abstract Nitrogen (N) losses from cropping systems negatively affect soil quality/fertility, crop yield, and the environment through its contribution to climate change and water pollution. İt possesses oil-water-atmospheric system challenges to both the too much and the too little N application countries. Soil and climatic factors are the critical drivers of N loss from agricultural systems as they influence major processes like nitrification and denitrification. Other N loss pathways include leaching, runoff, and volatilization. Nitrous oxide (N_2O) and ammonia (NH_3) gases are the two pollutants resulting from N fertilizers in crop production and represent N loss' significant pathway. Nitrous oxide is 300 times more a potent greenhouse gas than carbon dioxide, and it also depletes the ozone layer. Developing and adopting key strategies to mitigate N loss's extent will be critical for crop productivity and environmental management. İn this chapter, we highlight the potential solutions that can be adopted at a global and local level to manage N in the agricultural system. A linkage between N and climate change has also been reviewed.

Keywords Nitrogen loss · Mitigation · Agriculture · Climate change

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_2

1 Introduction

Agriculture is a source of nourishment for more than half of the world's population. Globally, plant nutrition of most of the available foods is supported by use of synthetic nitrogen (N) fertilizers (Zhang et al. 2015). A continued and adequate flow of N and other key nutrients for crop production has enabled farmers to boost farm productivity and meet food demands for a rapidly growing global population. Globally, there are two common N use scenarios: the too much and too little N scenarios. Nitrogen fertilization is a critical factor contributing to anthropogenic emissions of N_2O from agricultural soils (Bouwman 1996). The N_2O emission increases with increasing N inputs and decreasing/low nitrogen use efficiency (NUE). China case is a commonly used example of surplus nitrogen fertilizer application, coupled with low NUE and environmental pollution (Raghuram et al. 2020). The nitrogen use rate in China is estimated at 305 Kg N ha^{-1} $year^{-1}$ more than four times the global average (Harris 2018). Chinese croplands have an estimated total direct N_2O emissions of 313 Gg N_2O-N in 2007, and the contribution to N_2O by synthetic N fertilizers from cropping systems was 79.4% (Gao et al. 2011). On the other hand, in developing countries, especially those in sub-Saharan Africa, low fertilizer inputs of 0–12 kg N ha^{-1} are prevalent against the recommended possibility of 50 kg N ha^{-1} (Tsujimoto et al. 2019; Ntinyari and Gweyi-Onyango 2018a, b). Low soil N and low N inputs drive extensive land degradation due to N mining and negative N balances. In degraded soils, production of biomass is low, leaving the surface exposed for erosion and crusting and causing harm to the soil structure and declining of the content of soil organic matter. Across the two scenarios, managing N use remains critical to boosting yields and reducing environmental pollution.

N losses from agricultural systems negatively affect the ecosystem due to N cycle complexities (Cameron et al. 2013). Stuart et al. (2015) and Davidson et al. (2011) reported that in addition to reactive N (N_r) losses from agriculture environmental problems, the negative impacts of N_r are also some of the most difficult environmental problems to abate. This is because only less than 40% of the N applied to crops is taken up, leaving a more significant percentage prone to lose via different and complex pathways (Plett et al. 2020). Recently, N compounds in agriculture for food production have been linked to accelerated N pollutants in the environment. In agricultural production systems, available N for uptake is prone to loss through three principal pathways, including volatilization, leaching, and denitrification (Fig. 2.1). New evidence has shown that intensive agricultural production, including industrially produced N, has positive interactions with the environment and poses threats at local, regional, and global spatial scales. According to Fowler et al. (2013), the anthropogenic sources' magnitude relative to naturally fixed N is large and has doubled the cycling of N globally. Losses of N compounds into the environment cause degradation of water, air, and soil quality and contribute to increased human mortality (Liu et al. 2020). Specifically, N lost as nitrate (NO_3^-) through leaching pathways to groundwater and surface water has high risks to human health and aquatic life due to eutrophication and algal bloom effects (Khan

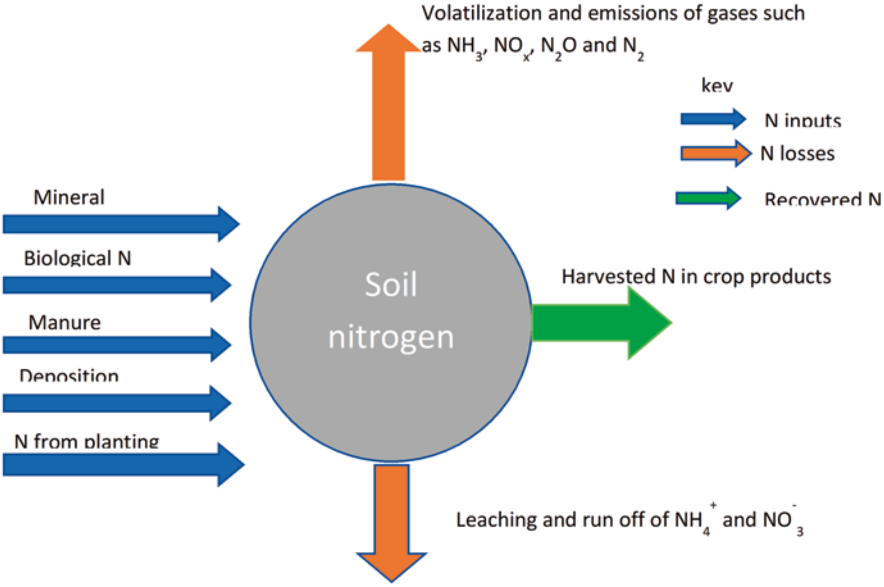

Fig. 2.1 An illustration of N sources into and out of the agricultural system (losses and out of the system). (Zhang et al. 2015)

et al. 2018). N can also be lost from the soil to the atmosphere in the form of N_2O which is a potent greenhouse gas with a global lifetime estimated at about 114 years (IPCC 2007). A kilogram (kg) of N_2O is 300 times more than carbon dioxide that causes depletion of ozone (Stuart et al. 2015),

Managing N losses in the cropping system by reducing the magnitude of applied N ending up unutilized is a potential strategy for improving nitrogen use efficiency (NUE) (Wallace et al. 2020). Sutton et al. (2009) argued that improving NUE to recommended range could provide a "win-win" scenario for crop yield and environmental sustainability. NUE can only be improved by increasing both temporal and spatial coincidence between N's availability in the soil and crop uptake, which has the ultimate potential of reducing N flows to the atmosphere and water bodies (Randall et al. 2008). In this chapter, more emphasis will be put on reducing N loss from applied fertilizers in cropping systems, factors leading to high risk of N loss, improving NUE, and mitigating climate change effect due to N fertilizer use.

1.1 Nitrogen and Climate Change

Nitrogen plays a direct and indirect role in short- and long-term global warming and cooling effects, hence climate change. For global warming effects to occur, N_2O results in the formation of tropospheric ozone that has short-lived GHGs with

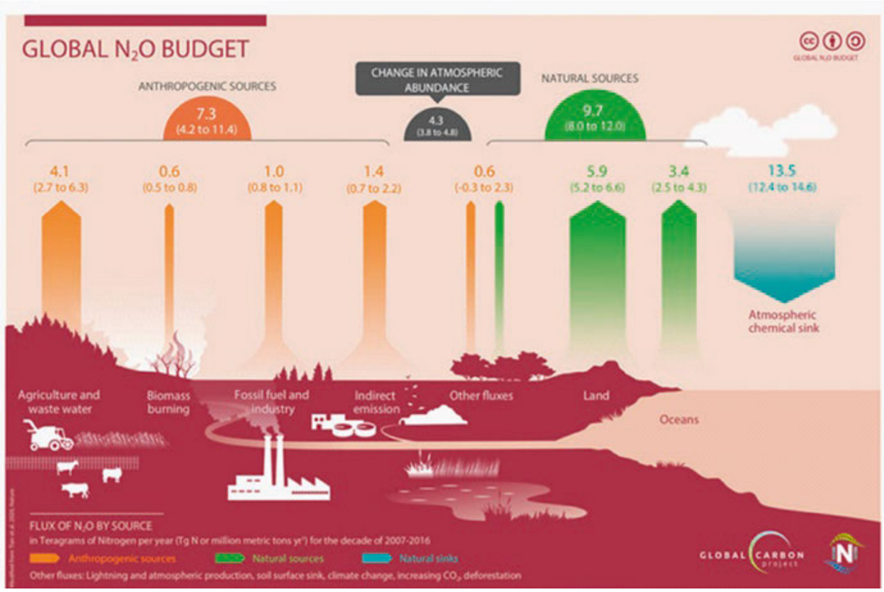

Fig. 2.2 Illustration of desirable range of NUE for minimal N loss. (Adapted from EUNEP 2016)

lasting effects. On cooling effects, N application causes sequestration of carbon (C) through increasing fixation of CO_2 by plants (Hungate et al. 2003). GHG emissions from applied N fertilizers cause both direct and indirect effects on the climate (Zaman et al. 2021). N_2O is a direct N loss pathway with the highest potential of trapping solar radiation in the atmosphere. NO_x emissions have indirect effects since their contribution to atmospheric reaction leads to degradation of ozone (O_3) (Cassia et al. 2018). O_3 causes a warming effect in the atmosphere's lower side, i.e., the troposphere, and a cooling effect in the upper atmosphere stratosphere (Galloway et al. 2008). Annually, N_2O is released in significant amounts and possesses a positive radiative force to store thermal radiation from the sun directly, hence the global warming effects (Fig. 2.2); a global N_2O budget is presented showing all potential gas sources, with agriculture being the most significant contributor. As calculated by Galloway et al. (2007), in over 100 years, the global warming potential (GWP) of N_2O is about 300 times larger than its equal mass of CO_2 hence making it a gas of more concern in agriculture. With these concerns affecting the globe drastically, there is a need to develop rational methods for saving the world from negative impacts of N use in agriculture through reducing its losses to the environment and at the same time without affecting crop yields either in developing or developed countries (Plett et al. 2020).

N management as climate change adaptation is a sustainable practice that promotes agricultural productivity. This practice includes crop diversification, alternate land-use management, and agricultural intensification. Managing N helps boost quality of crops that can be deteriorated by climate change (Zhang et al. 2016). For instance, when there is a high concentration of CO_2 in the atmosphere and lower availability of N in the soils, crops tend to have higher levels of carbohydrate and lower protein content hence deteriorating the overall quality of the harvested crops (Dong et al. 2018). However, with the current trend of alteration of N cycling processes, climate change impacts will continue to be felt in terrestrial and aquatic ecosystems.

2 Major Factors Leading to High Risk of Nitrogen Losses in Agriculture

2.1 Soil Characteristics

The type of soils significantly influences total fluxes of N_2O emitted from applied N sources. Clayey soils have reported more significant emissions than sandy soils, and also some N management practice could tend to increase emission from soils with fine textures. The high emissions of N_2O in clayey soils are influenced by micropores that increase anaerobic microsites, consequently increasing denitrification on nitrates to N_2O emissions (Signor and Cerri 2013). The process of producing N_2O by nitrification is favored by low O_2 partial pressures that are not adequate for completing the entire nitrification process of NH_4-N to NO_3-N (Goreau et al. 1980;Bollmann and Conrad 1998), a process commonly associated with nitrifier denitrification (Bollmann and Conrad 1998). On the other hand, denitrification is an anoxic process which increases with decreasing O_2 partial pressure in the gas phase (Smith 1990). This implies that the two processes rely on triggers of limited oxygen availability. Soil pH is a chief modifier of N_2O emission in cropping systems. The nitrous oxide reductase is inhibited in low pH soils and in the presence of oxygen (O_2). At low pH, the rate of N_2O production would be relatively higher because less of the N_2O is reduced to N_2. The soil pH also influences the denitrification process and N_2Oproduction (Signor and Cerri 2013). Production of N_2O is highly favored by a high concentration of nitrates (NO_3-) and low pH in soils. High carbon (C) content increases the production of N_2O gases because it influences nitrification and denitrification reactions through stimulation of microbial growth and activity. A low C/N ratio in the soil surface prevents immobilization of N and makes N more available for nitrification and denitrification, leading to high emissions of N_2O (Signor and Cerri 2013). The exchange of cations in the soil contributes to the retention of ammonium (NH_4) ions in the soil surface and organic matter through electrostatic attraction. This mechanism helps store NH_4^+in grounds and reduce the solution of the NH_4^+in those soils. Cation exchange capacity (CEC) also plays a role in buffering the soil against pH changes, making ammonia volatilization relatively low, and reducing the impact of loss on applied N. Tropical ecosystems act as an essential source of N_2O (and NO) and are most often linked with phosphorus limitation other than being N limited, a perfect example being the Northern Hemispheric terrestrial ecosystems. Application of N fertilizers in such phosphorous-limited ecosystems leads to generation of NO and N_2O fluxes that are 10–100 times higher when compared to similar fertilizers in N-limited ecosystems (Hall and Matson 1999). In addition, N_2O emmission from soil are regulated by both temperature and soil moisture therefore have a likelihood to adapt to climate change in respects to rising temperatures and limitation of water (Frolking et al. 1998; Parton et al. 1998).

2.2 Temperature, Moisture, and Aeration

Soil temperature and moisture are essential factors influencing nitrification and denitrification as they affect microbial activities (Zaman and Chang 2004). N conversion rate is relatively low under mild temperatures, and as temperature increases, exponential rates of N_2O are experienced as a result of high conversion rates of available N (Laville et al. 2011). This firmly explains the seasonal and temporal variations of N_2O fluxes in soils associated with soil and air temperatures. In principle, when the soil moisture is high, the level of N_2O emissions increases because both nitrification and denitrification are enhanced by moisture availability (Laville et al. 2011).

3 Management Strategies to Reduce Nitrogen Losses from Agricultural Lands While Maintaining Crop Production

3.1 Improving Nitrogen Use Efficiency

The overall strategy for managing N for reduced losses and enhanced associated crop yields is achieved through improved nitrogen use efficiency (NUE). Even with the potential negative impacts, elimination of N fertilizers in agricultural systems is not possible with the fact that they contribute to feeding half of the global population (Erisman et al. 2008), and the increasing population can only be supported through intensification. Therefore, there is a need to improve the efficiency of using N fertilizers. As reported by Lassaleta et al. (2014), global NUE reduced from 68% to 47 % in 2010 with an indication that more than 50% of the applied N to the soils is lost to the environment. Given that the NUE from soils is approximated to be 50%, there is critical opportunity to manage the N applied to soils and improve its efficiency. Improving NUE to the desirable range will help mitigate adverse effects of N losses from cropping systems and the environment (Powell et al. 2010). For regions with a high amount of N input application, judicious choice of fertilizers (nutrient source) and rate should be of critical interest to ensure NUE falls within the recommended ranges. As suggested by the European Union Nitrogen Expert

Panel (EUNEP, 2016), the ideal and desirable NUE lies in the range between 50 and 90%, whereas below 50%, NUE indicates the likelihood of applied N not properly utilized and prone to losses through leaching, denitrification, and volatilization processes**.** In developing countries, NUE values higher than 100% have been reported (e.g., Gweyi-Onyango 2018). The NUE levels exceeding 90% imply harvested N exceeding the applied N and pose risks of soil mining and soil health degradation. The following are some of the management techniques with a potential for reducing nitrogen losses while maintaining high yields.

3.2 Nitrification Inhibitors

After applying nitrification inhibitors, N fertilizers have shown success in different soil types and weather patterns in managing N_2O emission. The inhibitors function by limiting the conversion of NH_4 to N_2O by reducing the activity and population of *Nitrosomonas* and *Nitrobacter* bacteria in the soil (Alva et al. 2006). Nitrification inhibitors play a role in sustaining fertilizer availability to crops for a long time by delaying the process of nitrification, nitrate leaching, denitrification, and volatilization of NH_4 (Li et al. 2020). Stabilization of fertilizers through the use of inhibitors has also increased yield to a more significant percentage from 3% to 13%, which is a good indicator of NUE (Li et al. 2020). Other than increasing crop yield, stabilized N fertilizers have high chances of protecting the soils and climate in the long run (Wagner-Riddle et al. 2020). Measures to limit the growth of nitrifying bacteria also allow an opportunity to mitigate N loss through the application of nitrification inhibitors. For instance, spraying of inhibitors to grassland that has manure before cultivation is reported to delay nitrification and availability of NO_3^-(Duan et al. 2017). The nitrification inhibitors inhibit the conversion of $NH^+{}_4$ significantly and prevent NO_3losses through leaching (Dawar et al. 2021). The only challenge in using nitrification inhibitors between developing and developed countries is the high cost accompanied by the process (Subbarao et al. 2012). For instance, in sub-Saharan Africa (SSA), acquiring mineral N fertilizer is a challenge, and the mentioning of inhibitors becomes an additional burden to the region (Bessou et al. 2011). However, developed countries like Europe can easily acquire these inhibitors, hence standing a better chance to manage N losses in cropping systems properly.

3.3 Controlled- and Slow-Release Fertilizers

The type of fertilizer could determine the pattern of nutrient availability, uptake, and the potential for losses. Urea, which is a commonly used N fertilizer, has been reported to have NUE values of only 50% out of which 2–20% is emitted, 5–25% reacts with soil organic compounds, and 2–10% is lost through leaching into ground waters leading to environmental concerns (Savci 2012). N in urea is and later converted to nitrite and nitrate ions through the process of nitrification. The application of controlled-release and slow-release fertilizers ensures limited availability of N during the crop growth cycle, thus reducing potential losses through nitrification, denitrification, leaching, and volatilization (Tonitto et al. 2006; Mutegi et al. 2019). The main aim of controlled-release, slow-release, and stabilized fertilizers is that they synchronize N's amount with the demand of crop at a specific time of crop growth.

In an attempt to meet the crop N requirement by use of conventional N sources like DAP, urea, and CAN, splitting N to different phases of crop growth is recommended as a way of reducing N losses. With controlled-release fertilizers, the need for split applications is avoided as the fertilizer granules are coated with membrane that is made from polymer, plastic, or resin that limits release of nutrients very quickly (Wesołowska et al. 2021). Different membrane thickness makes availability of nutrients at different times hence matching with the crop needs. Controlled-release fertilizer is also referred to as controlled availability, metered release, coated, delayed release, or slow-acting fertilizer. Some of the examples of these fertilizers include the polymer-coated urea, polymer-coated NPK, and polymer sulfur-coated urea (Wesołowska et al. 2021). The rate of nutrient release by the CRF varies in specific plants depending on the metabolic requirements; therefore, the European Standardization Committee (CEN) task force has made certain recommendations on the use of CRF compared to other conventional fertilizers. The mode of release of CRF is defined in manner that 15% of nutrients are released in the first 24 hours, not more that 75% is released in 28 days, and at least 75% of the applied nutrients are release within the required time (Trenkel 2010). The adoption and use CRF have potential of improving NUE and reducing loss of nutrient through primary pathways of leaching and volatilization and contributing to minimizing the environmental pollution. It is also possible to decrease the fertilizer application rate by 20–30% of the recommended value to achieve the same yield (Gil-Ortiz et al. 2020; Trenkel 2010). According to the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), use of CRF is a great option to mitigation of N_2O emissions from fertilizers (IPCC 2007). Other results from intensive studies on CRF technologies have showed the potential to minimize losses of N from leaching, volatilizations, and emissions (Shaviv 2001; McTaggart and Tsuruta 2003), leading to an improvement of NUE and resulting to other benefits like reduced cost of labor and fuel costs (Shoji and Kanno 1994; Grant 2005). In a study by Gao et al. (2018), the average total N_2O and NO emissions in the controlled-release fertilizer treatment in the pot and field experiments decreased by 26.5 and 19.4%, respectively, relative to the conventional N fertilizer. The average N_2O and NO emission factors decreased by 32.1 and 24.8%, respectively, compared with the conventional N fertilizer treatment.

Slow-release fertilizer is defined to contain compounds that have low solubility with a complex/high molecular weight and chemical structure for releasing nutrients through decomposable compounds either chemically or through the microbial process (Shaviv 2005; Trenkel 2010). Slow-release fertilizers also release their nutrient load gradually by fertilizer nature but not bound by a membrane like the CRF (Guodong et al. 2017). The rate, pattern, and duration of N release from slow-release fertilizers are controlled by naturally occurring microbes or chemical processes whose activities are commonly mediated by temperature and moisture conditions. They include synthetic slow-release and organic slow-release fertilizers. Examples of synthetic slow-release fertilizers are N-Sure, a liquid fertilizer containing 28% nitrogen (28-0-0) (Cropvitality.com, undated). Other than having suitable fertilizers, the method of N application is also critical for high NUE and minimal losses of applied N. For example, broadcasting leads to loss of more N through volatilization and immobilization of N in the surface.

3.4 Diagnostic and Decision Support Tools

3.4.1 Remote Sensors and Normalized Difference Vegetation Index (NDVI)

Remote sensing can be used to determine spatial crop N status in a cropping season. The Soil Plant Analysis Development (SPAD) chlorophyll meter helps segregate locations. The SPAD meter is a resourceful tool for diagnosing the N status of crops (Lemaire et al. 2008). Some research has reported a strong correlation between the SPAD indicators and nutrition index of N (Prost and Jeuffroy 2007) and N concentration in plant tissues (Giletto and Echeverría 2013). It positively identifies mineral N deficiencies in crops (Sharma and Bali 2018). Using this technique, N fertilizer application can be tailored to avoid excess N application. However, due to cost, this technique is more common in developed countries and among large commercial farms in the developing countries. The reflective sensors have the potential to represent an approach of providing quick and nondestructive estimates of actual N status in plants (Sharma and Bali 2018). Through careful observations, near infrared (NIR) spectroscopy gives the content of leaf chlorophyll that can be used for early detection of the plant N deficiency. This implies that farmers applying this tool are capable of determining the right time that they can apply N in their crops and minimize unnecessary losses (Sharma and Bali 2018). Another technique is using low-cost remote sensing methods for scheduling N fertilizer applications. In this method, fertilizers are applied at small-scale operations coupled with detailed monitoring of both biotic and abiotic plant stresses. NDVI represents vegetation indices applicable in precision agriculture as a tool for crop management (Sharma and Bali 2018). NDVI values can indicate N uptake, yield prediction, and plant health and show a positive correlation between photosynthetic activity and N. Therefore, NDVI can assess the effects of fertilization depending on plant N contents and total plant biomass.

3.4.2 Use of Airborne and Satellite Imagery

In developed countries where large-scale farming is common, aerial and remoting sensing crop monitoring is common. The unmanned aerial vehicle (UAV) flights are used to detect N demand of crops and send a signal when the application is critical (Goffart et al. 2008). Some of the tools used in imagery, including Red Green Blue (RGB), combine red, green, and blue light to estimate green biomass and detect N status. Some infrared and thermal imaging cameras can predict nutrient-stressed crops and send signal to the growers to apply N. Aerial remote sensing services provided by some companies as diagnostic of crop nutrient deficiency in different cropping systems. Models of nitrogen application have also been developed to permit farm nitrogen management improvement (Samborski et al. 2009). The algorithm N model can obtain information through N sensors and guide the farmers to apply the right dose to crops, thereby increasing crop production and decreasing contamination of the environment by excessive N fertilization (Samborski et al. 2009). Data collected through satellite and imagery analyzes soil and fertilization data on spatial and temporal scales.

3.4.3 Web, Computer, and Phone-Based Decision Support Tools

Various web, computer, and phone-based algorithm-driven decision support tools like the Nutrient Expert (NE) and Nutrient Manager for Rice (NMR) support implementation of site-specific fertilizer management leading to improved NUE (Rurinda et al. 2020; Sharma et al. 2019). By use of decision support tools, it's possible to significantly reduce the fertilizer application rates through improved Fertilizer Use Efficiency (FUE) while sustaining or increasing crop yield levels (Wang et al. 2020). For example, the reduced N fertilizer recommendation generated by NE increased yield for 64% of rice growers and 77% of wheat growers in India (Sapkota et al. 2021). Similar trends were evident when fertilizer rates were reduced by use of NE recommendation in the Nigeria and Ethiopia sites (Rurinda et al. 2020). Through calculations based on 1594 maize and wheat trial sites in India, Sapkota et al. (2021) concluded that adoption of NE-based fertilizer recommendations in all rice and wheat fields in India would increase rice and wheat grain yield by 13.92 million tons, reduce N fertilizer consumption by 1.44 million tons, and reduce GHG emissions by 5.24 Mt CO_2-e per year.

3.5 Use of Cover Crops

Integration of catch crops and cover crops into the rotations significantly reduces nutrient leaching and runoff and minimizes the need to add mineral fertilizers. The use of leguminous crops as cover crops helps promote N fixation into the cropping systems, thus reducing the amount of fertilizer N input added to the cropping systems (Wittwer and van der Heijden 2020). The cover crops have also proved to be effective in reducing indirect emissions of N_2O (Ntinyari and Gweyi-Onyango 2021). Their ability to reduce nitrate leaching and indirect N_2Oemission is facilitated by reduced available N in the soils. This is because they take up N that is left in the soil after harvest of the main crop. Cover crops depleted the nitrates pools in the soils, a significant denitrification substrate, consequently reducing indirect N_2O emissions (Kim et al. 2017). Intercropping legumes with cereal crops is another strategy that can be used to reduce NO_3-N losses in agricultural systems. For example, in an intercrop between corn-soybean, the soybean will help take up residual N in the field with high chances of increasing fertilizer recovery and reduce potential leaching, erosion, and N_2O losses of available N in the soils (Abdalla et al. 2019). Further, the leguminous cover crop species fix nitrogen, reducing the N fertilizers that farmers need to apply to meet the requirements for the associated crop. In some circumstances, cereal grasses are recommended for trapping and retaining N in the soils. Their roots remain active even in cooler temperatures, making them more effective in preventing N losses through leaching (Abdalla et al. 2019).

3.6 Adoption of Conservation Tillage

Conservation tillage practices such as minimum till, ridge till, multi-till, and strip till practices have been proven effective in reducing N losses, specifically through reduced surface runoff (Zhang et al. 2020). Conservation tillage increases surface residue and limits the incorporation process of organic matter and nutrients improving water infiltration and reducing runoff losses (Ntinyari and Gweyi-Onyango 2021). Conservation tillage reinforces the soil temperature and moisture that could otherwise influence the microbial activity of nitrification and denitrification, thereby minimizing the possibilities of N loss (Zhang et al. 2020). Furthermore, the practice of conservation agriculture encourages retention of crop residues on the farm. High C/N ratio stimulates N immobilization and reduces the availability of nitrogen substrate for denitrification and nitrification, thereby minimizing N_2O emissions (Mahajan et al. 2008).

3.7 Manure Application and Management

Application of manure to the crops when the soil temperatures are low is encouraged to reduce the chances of nitrifying through biological activities and subsequently loss of N either through leaching or denitrification (Rotz 2004). Soil temperatures below 10 °C reduce nitrification rates; however, during winter, when the temperature is extremely low, manure application is discouraged as freezing temperature impedes N's binding in the soil and lowers the rate of infiltration that can result in runoff. Figure 2.3 demonstrates the extent of N loss at each stage of

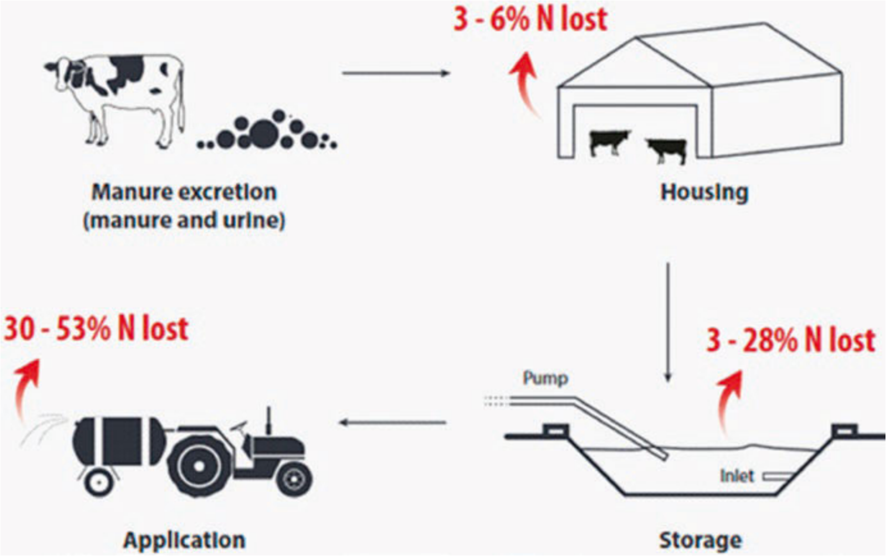

Fig. 2.3 Nitrogen emission loss from a typical dairy facility. (Adapted from Aguirre-Villegas et al. 2014)

manure preparation, storage, and application point. The application of manure to already established plants in the field is another way farmers can minimize leaching loss because growing crops will utilize available N (Hernandez and Michael 2012).

Researchers have developed empirical and mechanistic models to predict N loss during handling and application of manures in the fields. Following manure application in the cropping systems, mechanical models have been applied to simulate N's transformations, including nitrification, denitrification, and predicting the quantity of nitrate leaching and N emissions into the atmosphere (Cannavo et al. 2008). The models improve understanding of dynamic processes involved in manure management by predicting and quantifying N-associated losses (Rotz 2004). Sophisticated models combine losses of N with production components to predict environmental and economic implications for management strategies (Chlingaryan et al. 2018). Modeling can be performed beyond farm level to country level to show the impact of practices on ammonia volatilization, nitrous oxide emissions, N leaching, and runoff. Additionally, a combined application of organics like manures, crop residues, green compost, biofertilizers, and inorganic fertilizer to the soil in a synergistic manner can substantially improve N's use efficiency (Mahajan et al. 2008). The addition of manure into the field with other organic sources minimizes N loss by the volatilization process.

3.8 Site-Specific Nutrient Management

Site-specific nutrient management (SSNM) is a strategy that enhances yield by guiding farmers to improve the efficiency of fertilizer use (Dobermann et al. 2002). Best management practices (BMPs) are the key most crucial strategies toward improving N management and reducing associated losses at the SSNM level. BMPs base its activities on other principles, including system analysis, N budgeting, and integrated N assessments. For BMPs to be effective, specific farm prioritization is required to achieve minimal losses by minimizing fertilizers. Specifically for developed nations, greenhouse gases such as N_2O are reduced by up to 50% (Dobermann et al. 2002). The 4R nutrient stewardship (which stands for application of nutrients from the right source at the right rate, at the right time, and at the right place) is used as the framework for optimizing the efficiency of soil nutrients (Johnston and Bruulsema 2014). The right product refers to the source of fertilizer needed by the crop and the soil type to match a balanced nutrient supply to promote crop growth. In the context of N, the correct rate refers to a match between the amount of N that the crop requires and what is actually supplied from the soil and external sources (Dobermann et al. 2002). Adhering to the right rate controls application of too little or too much N thus avoiding excess N that could be lost with erosion water, as leachate or as N_2O. Further, it avoids application of too little N which is one of the fundamental causes of negative N balances and land degradation. N application's right timing ensures fertilizer is applied and made available to crops in accordance with the crop growth cycles and nutrient requirements at different developmental stages (Dass et al. 2014). Split N application allows the farmer to apply recommended N at different stages (basal application and top dressing) of crop growth, thus reducing the amount that could be lost with one-time application strategy. Right placement refers to placing nutrients at distances where crop roots can easily access them and to minimize losses. Incorporating N fertilizers into soils is highly recommended than application to the surface as an ideal way to prevent additional losses (Dass et al. 2014). Other than increasing yield due to optimized N balance into the soils, N_2O is significantly reduced due to a lower amount of total N applied to cropping systems, hence minimizing volatilization and leaching losses.

3.9 Stakeholder Involvement and Integration

Achieving improved management of N requires implementing policies that can reduce the losses (Zhang et al. 2015). For instance, in some countries like China, policies toward zero synthetic fertilizer use by 2020 have been enacted. This kind of policy is aimed at minimizing excess N because soils that are saturated with N pose a threat to air and water quality. On the other hand, in developing countries like in SSA, there is a need for policies to support increased N inputs into the soils to control soil degradation and, consequently, enhance crop yield. Policies can be made in specific countries/governments to enforce the N resource's suitable measures (Oenema et al. 2011). At regional levels, governments can also participate in trans-boundary N pollution management through development of policies applying at regional scales (Oenema et al. 2011). For developing regions, managing the trans-boundary nature of pollution in the environment and creating level-playing fields could increase N management measures' effectiveness.

4 Tools for Integrated Management of Nitrogen

Toolbox for managing N management approaches contains critical tools that are specific to one integration dimension. The tools to be selected in this management context include system analysis, communication, nitrogen budgeting, logistics and chain management, stakeholder dialogue, integrated assessment modeling, cost-benefit analyses, and best practices management (Shahzad and Ahmad 2019). Systems analysis is the first point in developing integrated approaches through provision of required information. It also identifies and quantifies components, flows, actors, processes, interactions, and inter-linkages between and within systems (Shahzad and Ahmad 2019). This tool is applied in a scientific-policy interface to combine both recommendations from science and policy needs. Communication is another tool applied in integrated N management for transferring information and creating awareness. The meanings, purpose, actions, and targets of integrated N management strategies are explained to all involved stakeholders through communication. Communication makes transparent the concept and terms of "integrated" and "management" that create some ambiguity hence promoting the adoption of proper measures and practices (Shahzad and Ahmad 2019).

N budgeting is another essential tool for improving the management of N losses in agricultural systems. N budgets quantify differences between various N inputs and outputs within a system (Oenema et al. 2011). N budgeting makes it easier to identify the significant N loss pathways and sources of N pollution. In previous studies, N budgeting has been shown to help farmers and policymakers detect pollution by creating an easy way of understanding the existing sources. However, before applying these tools, there is a requirement to have a uniform definition to circumvent any bias in the process (Oenema et al. 2011). Life cycle assessment (LCA) is another approach similar to budgets that helps in accounting for emissions and resources during a given product's life cycle. Both LCA and N budgets can apply to scientists and various practitioners.

Integrated assessment modeling is another tool that includes cost-benefit analysis, target setting, and ecological footprint analyses. It encompasses cause-effect relationships through an interdisciplinary process of quantifying and analyzing current situations and future trends (Leach et al. 2017). In this tool, scientists can develop a policy interface that can be applied in recommending actual and prospective N in the ecosystems if no mitigation practice is applied and the implication to specific systems (Shahzad and Ahmad 2019). Logistics and chain management is another tool that involves planning and management of activities and information relevant to N sources, installation, and point-to-point source management. These apply specifically to fertilizer-producing companies and animal feeds transporter and distributors. Stakeholder dialogue plays a critical role in creating a linkage between people with similar competing interests in managing N and other sources best. Stakeholders give way forward to dealing with N management uncertainties in all spatial scales (Leach et al. 2017).

4.1 National Nitrogen Strategy

Developing a national strategy can contain N use's adverse effects on the environment (Manap and Voulvoulis 2015). This strategy applies both to developing and developed countries in which targets for reaching acceptable Nr levels into the territory are clearly defined. The targets need to be based on creating a resilient ecosystem through interactive scientific forums and other societies with common interests. This process can be found in the modeling of N inputs and their impact on the environment, and the set target for N input should be guided by the set targets for agricultural sectors (Bouraoui and Grizzetti 2014). The N strategies should combine all other existing measures for reducing N losses and identify both medium- and long-term actions (Halberg et al. 2005). The strategy needs to be underpinned with an ambitious action program that monitors and evaluates the measures regularly. However, for this kind of strategy to be successful, it must be implemented alongside financial and human resources supplies to enhance its success. The plan should be rolled out as an integrated N mitigation and administered as a national environmental program.

The agriculture sector is the largest single source of N emissions and should play a pivotal role in minimizing the losses. There is tremendous potential to reduce these losses in the agriculture sector by adopting the existing legal framework and probably strengthening them (Mohanty et al. 2020). There is a need to create reforms to current agricultural policies and strengthen legal regulation to use N inputs. This applies to developed countries and developing countries without any legal framework governing nitrogen fertilizer (Ekardt et al. 2018). There should be taxation on surplus N input into the ecosystem especially from developed regions where N input is surplus compared to developing regions with deficits. Imposing N surplus taxes would significantly reduce emissions in a cost-efficient manner (Ekardt et al. 2018). This can be promoted by creating a farm advisor, promoting technical measures to enable the growers to reduce emissions, and promoting sensitive standards to natural areas.

5 Conclusions

N loss and subsequent pollution have remained a global challenge affecting both developed and developing countries. Both scenarios of regions with more N input and those with less/little N input require mitigation strategies that are sustainable to enhance N's efficient use to both cropping systems and reduce environmental impacts. Understanding key factors contributing to increased N losses, such as soil characteristics and climatic features, remains key to lessen N loss challenge. Through management of N losses, there is a promising potential to minimize climate change effects, mostly felt through emissions of meaningful greenhouse gas such as N_2O. Possible solutions that can be adapted for both regions include modeling assessment, policy and regulations, site-specific N management, use of cover crops, conservation tillage, proper manure use and storage techniques, national nitrogen strategy, improving NUE, use of better crops for nitrogen scavenging, and use of remoting sensing among others. The availability of these tools and options is light to the global community, focusing on achieving sustainability in N use.

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Chapter 3
Critical Analysis and Evaluation of Groundnut Value Chain for Revamping Its Production for Global Food Security

Michael Ajanja Sakha, Joyce Jefwa, and Joseph P. Gweyi-Onyango

Abstract This paper sheds light on groundnuts value chain to recognize key attributes such as chain actors and the relationships among them, including production and flow of goods through the chain to the destination. This is because groundnut is a major agricultural crop globally which is being predominately utilized in peanut butter, candies, oil, flour, biodiesel, and a host of other home products. When used as a cash crop, it somewhat gives high profit from a small piece of land. The chapter critically highlights the main stages of groundnuts starting with input suppliers, producers, traders, processors, exporters, importers and consumers. Also, it outlines what has to be implemented by each stakeholder in the industry in order to revamp the value chain capacity to achieve global food security.

Keywords Critical analysis · Evaluation · Value chain · Implemented · Food security

1 Introduction

Groundnut (*Arachis hypogaea* L.) is also known as peanut, earthnut, or goober. It is a legume found in the sub-family Papilionaceae. This sub-family is the dominant member of the family Fabaceae (Pande et al. 2003). It acquired its name from two Greek words, *Arachos* which means a weed and *hypogaea* which means an

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_3

underground chamber (Holbrook and Stalker 2003), that is, a weedy plant in possession of fruits underground. By virtue of its subterranean fruiting pattern, groundnut is widely referred to as the "unpredictable legume". The plant is unusual because its flowers are located above ground, while the pods are produced underground. Its origin can be traced back to South America, and it is has since been grown in the tropics, subtropics, and temperate countries between 40º N and 40° S (Pattee and Young 1982). In these areas, groundnut is widely cultivated as a rain-fed crop on soils with insufficient nutrient and by resource-poor farmers. Also, these areas experience high incidences of biotic and abiotic stresses.

The crop is currently being cultivated in the USA, India, China and many areas in Africa. Other high producing countries include Nigeria, Senegal, Sudan and Argentina (Freeman et al. 1999). China and India jointly are the world's chief groundnut producers which represent about 50% of the production and 52% of the growing area. There are four commonly grown groundnut types worldwide, and these include Spanish, Runner, Virginia and Valencia (Edinformatics 2005), although 81 species have been reported (Krapovickas and Gregory 1994; Valls and Simpson 2005; Valls et al. 2013). Developing nations account for 92% of the total global groundnut production (Talawar et al. 2005).Furthermore, this crop is being grown on about 21.8 million hectares of land worldwide. FAO (2011) reports showed that groundnut global production added up to 38.6 million tonnes, which is 95% of what was produced in developing countries. Compared to other smallholder crops, groundnuts are known for their heartiness and can generate adequate yields under unfavourable conditions where other crops may fail (Ojiewo et al. 2020).

In many countries in Asia and Africa, groundnut is produced by semi-subsistence farmers without irrigation and other agricultural inputs other than land and labour (Freeman et al. 1999). As a result, the production is about 700 kg ha^{-1} with a notable variation yearly. On the other hand, in the USA, Australia, Brazil, China, Argentina and South Africa, the crop is produced on a commercial scale using improved varieties, modern crop production practices and recommended inputs. Therefore, in these regions, the yields are greatly higher at about 2–4 t ha^{-1}, and they are more steady than in semi-subsistence systems (Freeman et al. 1999). Groundnut is an increasingly important crop to global food security and smallholder production systems (Toomer 2018; Stalker 1997). This is because it is a highly nutritious legume and also it contributes to the diversity of smallholder production portfolios since it is also used in rotations and intercropping systems. The crop is primarily cultivated since it consists of protein (10–20%), edible oil (40–60%) and carbohydrate even though it is very rich in essential minerals and vitamins (Pandey et al. 2012; Suchoszek-Lukaniuk et al. 2011). Kumari et al. (2012) reported that it is extensively utilized as an edible oil globally and is ranked third among all the edible oils. Its oil hold nearly all the macronutrients, namely, calcium (Ca), magnesium (Mg), phosphorus (P) and potassium (K), as well as important micronutrients like zinc (Zn) and iron (Fe). In terms of vitamins, it largely consists of B vitamins, such as riboflavin (B2), thiamine (B1) and niacin (B3) and tocopherol but is deficient in fat-soluble vitamins A and D and almost lacking in vitamin C (Nagaraj 1995). Furthermore, the main by-products of groundnuts that are oilcake and haulms are principally animal feed. This is because haulms carry 8–15% protein, 1–3% lipids, 9–17% minerals and 38–45% carbohydrate. Also, its outer shell is used in making particleboards, as fuel or as carrier materials in fertilizers and the feed industry. Importantly, groundnut is capable of fixing atmospheric nitrogen (N) in the soil through mutual relationship with soil bacteria rhizobia. Therefore, this crop should be adopted by resource-poor farmers in particular those that do not have means to enrich the soil through fertilizer amendment.

Groundnuts play an integral role in the livelihoods of the majority of the population, particularly the rural households. This is because it yields about 3500 kg/ha (African Institute of Corporate Citizenship 2016), although most countries are unable to reach this production level, plus some of the produce ends up being lost along the value chain. Taking into account the rural and urban consumption, its industrial use and the export demand, current demand is likely outstripping. This called for a critical analysis and evaluation of groundnut value chain to streamline it for global food security.

2 Groundnut Value Chain and Its Development

The term value chain analysis refers to the process of breaking entire chain of activities into its constituent parts so as to better understand its functioning and structure. Value chain of groundnut in this chapter comprises of activities that take place at various levels beginning with input suppliers continuing through production, product handling by traders, the industrial application, processing, exporters up to the consumers. Value chain development requires a concerted effort of stakeholders on issues such as product quality and safety enhancement; development of enterprises; quantitative measurement of value addition; promotion of coordinated linkages among farmers, processors and retailers; and upscaling of competitiveness of individual enterprises in the market (Trienekens 2011). Therefore, for the value chain to work effectively and efficiently, there must be concerted effort from the entire stakeholder in each value chain stage especially on how uniquely they handle their roles. It has been revealed time and again that high involvement in the process by all actors tends to cause better outcomes and a substantial sense of ownership (Fig. 3.1).

3 Components of the Value Chain

3.1 Input Suppliers

Groundnuts by and large require few inputs, making it suitable for production in low-input farming systems by smallholder farmers (Smartt 1994). Main inputs required for its production include skill and energy of the farmers, and without their

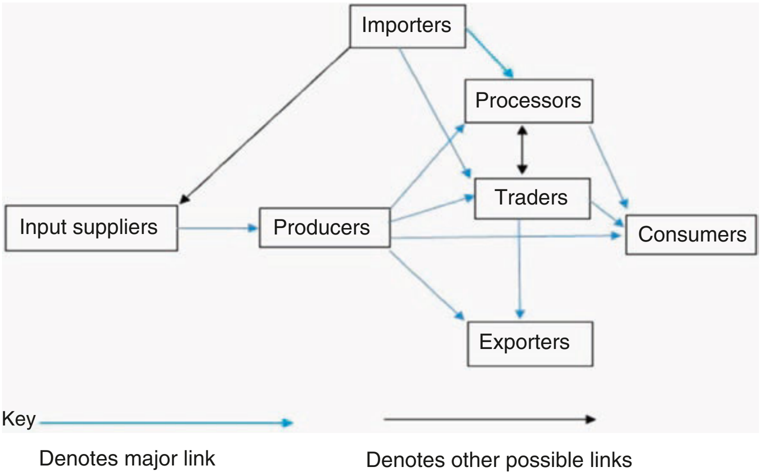

Fig. 3.1 Groundnut value chain

willingness, knowledge and labour, groundnut production would seize, as well as certified seed of suitable varieties, fungicide to dress the seed before planting, lime to correct soil pH, basal fertilizer, gypsum for top dressing and shelling equipment to ensure that farmers sell shelled nuts to increase their returns and labour. Furthermore, adoption of mechanization and irrigation should come in hand with the best equipment and skills. Ultimately, inputs should be provided using broad-based formal and informal channels to encourage access, availability and affordability. On the other hand, the channels should have the capacity to detect counterfeit products (such as seeds, fertilizer and pesticides) and other contaminated agricultural farm inputs.

3.2 *Producers*

Globally China is the chief producer of groundnuts, producing approximately 41% of the total output. In 2018, groundnut production reduced in India, the USA and Senegal due to adverse weather conditions, especially due to the effects of erratic rainfall (Intelligence 2021). Come 2019, the Republic of China was the highest producer recording about 17.5 million metric tonnes. This was followed by India, Nigeria, and the USA with approximately 6.8, 3.0 and 2.5 million metric tonnes, respectively (Table 3.1). However, Asia and South America are holding big market size for groundnut at global scale while Greenland, Australia and New Zealand holds small market size as indicated in Fig. 3.2. Groundnut producers produce a mixed bag in terms of quality, and this quality determines the marketing channel and ultimate market. Therefore, to revamp its production, producers must change their production practices such that producers should adopt usage of improved varieties, that is, those that are high yielding with pest and disease tolerance and drought

Table 3.1 Peanuts world production

Rank	Country	Percentage of world production (%)	Production (1000 MT)
1	China	37	17,500
2	India	14	6700
3	Nigeria	8	3900
4	USA	6	2782
5	Sudan	4	1800
6	Senegal	3	1600
7	Burma	3	1550
8	Argentina	3	1350
9	Tanzania	2	1100
10	Indonesia	2	970

Source: USDA (2021)

Fig. 3.2 Global peanut market: market size by region, 2019

resistance (Okello et al. 2013) among other important attributes (Atlin et al. 2017). Also, since groundnuts are 99% open pollinated plants, seed saving is effective for up to ten production cycles. That is five years assuming two cropping seasons per year (Jelliffe et al. 2018). Therefore, after recycling seeds for few years, reduction in yield vigour is expected due to the challenges of inbreeding. This can only be managed effectively through adoption of genetically improved pure seed stock. Breeding programmes should also focus on other groundnut attributes such seed and shape size for confectionery purposes, amount of oil and protein content, good shelling capacity, adaptability to climate change and various soil types, maturity period (i.e. shorter to medium) and suitability for mechanize harvesting. Mainly the breeding programme should focus their attention on the preferences of the end user.

Furthermore, proactive innovations must be put in place by the government and relevant agencies for aflatoxin control, which would require provision of sustainable incentives to farmers to achieve the right standards. Also, the producers should be organized in manageable groups which would facilitate flow of agricultural extension and outreach.

3.2.1 Recommended Nutrients for Groundnuts

Groundnuts provide high and quality yields when best varieties are cultivated on nutritious soils (Veeramani and Subrahmaniyan 2011). This is because this crop is distinctive in a manner it acquires its nutrients from the soil such that its seeds grow by way of nutrients it accumulates directly from the surrounding soil instead of those that are transported from roots to shoots and then be translocated back to the seeds (Table 3.2).

3.2.1.1 Primary Nutrients

Phosphorus (P) is an important nutrient for groundnuts since it enhances root nodulation, biological nitrogen fixation (BNF) and residual soil nitrogen content (Yakubu et al. 2010). Also, this element sufficiently contributes to healthy and effective root growth (Mitran et al. 2018). In general, P insufficiency for this crop can be corrected easily through P fertilizer amendment because the crop grows well on sandy-clay soils which are known to possess a major challenge of fixing P. On the other hand, P fertilization in addition to provision of enough P for the plants also increases the available P in soils since groundnut plant requirements and removal are considerably low (Gascho et al. 1992).

Potassium (K) K is the second most accumulated nutrient by groundnuts (Tasso et al. 2004). The nutrient takes part in various metabolic functions within the plant, for example, it aids in photosynthesis and assists in protein synthesis, enzyme activation and functioning of stomata (Hawkesford et al. 2012). Moreover, it regulates carbon dioxide and adenosine triphosphate (ATP) production (McKenzie and Pauly 2013). Also it plays a key role in fixation of atmospheric nitrogen and translocation of photosynthate from the leaves to the root nodules (Savani et al. 1995). Groundnuts usually respond meaningfully to application of K fertilizer in soils with low levels

Table 3.2 Nutrient uptake/ removal in groundnuts (kg/ha)

Plant part	Yield	N	P	K	Ca	Mg	S
Pods	3 t/ha	120	11	18	13	9	7
Vines	5 t/ha	72	11	48	64	16	8
	Total	192	22	66	77	25	15

Source: (Gascho and Davis 1994a, 1994b)

of potassium (<1.5 $mmol_c dm^{-3}$). Therefore, several studies have underlined the significance of K fertilization on groundnuts, emphasizing on its effect on plant growth, nutrition acquisition and production (Pradyut et al. 2006; Reddy et al. 2011; Sharma et al. 2011; Lobo et al. 2012). To this end, Dahdouh (1999) revealed that K fertilizer application up to 48 kg K_2O ha^{-1} enhanced substantively the amount of pod, oil percentage in the seed and groundnut shelling percentage.

Nitrogen (N) N is the most required mineral element in all farming systems because it's part of the biochemical and physiological processes of all the plant (Pourranjbari Saghaiesh et al. 2019). Huang et al. (2017) reported that farms with inadequate N (<10 kg ha^{-1}) before planting should be improved through the addition of a starter N for better yield and yield components of dry pea. However, application of higher rate of N fertilizer negatively affects nodulation and biological nitrogen fixation (BNF) of legume crops (Aslani and Souri 2018). Some of the factors influencing N supply to groundnuts are fertilizer type, variety, presence of inoculum, crop rotation, soil type, soil moisture and temperature (Gascho and Davis 1994b).

3.2.1.2 Secondary nutrients

Also in order to get high-quality groundnut yields, secondary nutrients are very important. Key secondary nutrients are discussed below.

Calcium (Ca) Ca is the most critical element in the production of groundnuts and in numerous regions globally, and it is the most limiting factor. Groundnuts have an extraordinary demand for Ca element from the surrounding soil during its growth period. The most important groundnut morphological characteristics that affect Ca element uptake by the pods include volume of the pod, number of days to maturation of a pods, shell thickness, surface area of the pod and specific shell weight (Kvien et al. 1988).

The high Ca is not for healthy growth but for enhancement of well-filled pod and high-quality seed (Gascho and Davis 1994a, 1994b). Therefore, sufficeint amount of S in plant available form in pods environment below ground is crucial for attainment of both high yield and oil content. Adequate Ca in soil levels for production of high-quality peanut kernels ranges between 600 and 800 mg kg^{-1} in the fruiting zone (0–10 cm) (Sumner et al. 1988). The soil test levels vary from one variety to another, for instance, it should be about 450 lb/A for runner type, while this almost doubles for Virginia type. Actually smaller-seeded varieties because of their large surface area to volume ratio require low soil Ca than the large-seeded types. The soil factors that affect Ca nutrition of groundnut include soil moisture content, soluble Ca, exchangeable Ca and the type of minerals present in soil (Keisling and Walker 1982).

In the soil, groundnut has the unique characteristics of absorbing Ca by developing pegs and pods. As Ca is moderately immobile in plants and is not translocated in abundant amounts to the fruiting organs (Meena et al. 2007), therefore, Ca should

Table 3.3 Response of groundnuts to magnesium application

Magnesium treatments (Kg ha^{-1})	Groundnut yield (q ha^{-1})	Response (%)
Control	13.80	–
10	16.71	21.00
20	17.90	29.70
30	19.54	41.60
CD (P=0.05)	2.82	–

Source: Lal and Suresh (1999)

be applied routinely in the form of gypsum during pegging especially on sandy soils for rapid replenishment of soil. On the other hand, Ca deficiency results in a high number of aborted seeds (empty pods or “pops”) and poorly filled pods (Ntare et al. 2008), blackened plumules, low seed germination and poor disease resistance (Gascho et al. 1994b).

Magnesium (Mg) Groundnut responds well to Mg application, and percent response ranges from 21.0 to 41.6 % (Lal and Suresh 1999) as shown in Table 3.3. Mg plays a major role in groundnuts: it is part of the photosynthesis, it activates many enzymes required for groundnut growth and it balances the nucleic acids.

Mg deficiency symptoms include intervein chlorosis which is usually characterized by plant yellowing between the veins while the veins remain green, leaves sometimes change colour from pink to light red, and they may curl upward along the margins. The Mg deficiency in soil can be corrected using dolomitic lime when lime is a requirement. On the other hand, when lime is not needed, soluble sources of magnesium are utilized. Most ordinary soluble sources of Mg to apply as fertilizer are magnesium sulphate (Epsom salt) containing 10% Mg and 14% S; sulphate of potash magnesia (K-Mag) containing 11.2% Mg, 22% S and 22% K2O; and magnesium oxide (Magnesia) containing 55% Mg, also known as magnesia.

Sulphur (S) Groundnut is a sulphur-loving crop since it plays a critical role in its metabolism and chlorophyll formation; it influences groundnut productivity especially in addition to phosphorus, nitrogen and potassium. Also, it promotes nodulation thereby aiding in nitrogen fixation. Additionally, S is reported to increase fruit maturation (Bromfield 1973; kernel weight; Weiss 1983). S requirement for groundnut is high during the early growth stages.

Groundnut is reported to have the capability of absorbing on an average about 11–22 kg of sulphur so as to be able to produce 1 tonne of seeds (Meena et al. 2007). Therefore, sufficeint amount of S in plant available form in pods environment below ground is crucial for attainment of both high yield and oil content. This can only be achieved by incorporating S fertilizers in groundnut cropping systems. More so because positive response of S fertilizer application to groundnuts was highlighted by Ramdevputra et al. (2010) and Dash et al. (2013). Also Schonhof et al. (2007) showed that sulphur deficiency has been reported globally with consequent low crop response, especially for oilseed crops such as peanuts. In developing kernels,

Table 3.4 Response of groundnuts to sulphur in different states and soil types

State	Soil type	S rate (Kg ha^{-1})	Response (%)	References
Bihar	Red sandy loam	30	27.0	Sakal et al. (1996)
Tamil Nadu	Clay loam	22	23.9	Kamala Thirumalaisamy (1986)
West Bengal	Sandy loam	30	22.0	Bandyopadhyay et al. (1998)
West Bengal	Red and lateritic	30	19.4	Biswas and Tewatia (1991)
Rajasthan	Loamy sand	60	59.6%	Yadav et al. (2019)

Modified from Meena et al. (2007)

the interval between 5 and 35 days after pegging is identified as the period of active filing. Sulphur can be applied as gypsum, ammonium sulphate, potassium sulphate and sulphur powder. However, Keerati-Kasikorn (1985) reported that there was no difference among the kinds of sulphur fertilizer, although time of S fertilizer application was more important than the amount applied (Table 3.4).

Application rate of these fertilizers varies from one region to another as influenced by available soil nutrients. Also, important agronomic practices that are achievable and economically applicable should be encouraged in peanut-growing areas. In general, just like in production of other crops, soils for cultivating groundnuts should be analysed before fertilizer is applied. It recommended to test the top 3 inches or the "pegging zone" of the soil.

Post-harvest Activities Carried Out by Groundnut Producers on Farm After Harvesting At harvesting groundnuts plants should be dunged out of the soil very carefully to prevent nut breakages and some remaining in the ground. The harvesting activity should be done at the right time when a good percentage (90%) of the nuts are firm, dry and brown on the outside. In particular at maturity, the inside of the pods should be greyish in colour, and some rattling must occur when pods are shaken. After harvesting, the pods are supposed to be ripped off from the bushes, followed by drying for a period of another 7–10 days to about 10% moisture. Thereafter, shelling is done properly either by hand or in large scale using the right equipment. Broken, dirty or damaged nuts are discarded since they lower the quality and hence the selling price. Also poorly dried groundnuts as well as dirty ones during storage pick contaminants such as fungi (various moulds) which are very devastating.

3.3 Traders

A common feature in all major groundnut-producing countries is the government's effort to manage groundnut value chain. This is achieved through intervention of commodity pricing and marketing that directly influences prices which further increases producer's income. However, the patterns of intervention by the government differs between developing and developed countries. In general, suggested government prices and marketing policies in developing countries discriminated against the groundnut sector by directly suppressing producer prices, or sometimes in some instances, the industry is unregulated. In developed countries, the groundnut sector is more robust since government policies protect the value chain through several price support policies and quantitative restrictions on imports. A good example is the introduction of quotas that protects the domestic production (Freeman et al. 1999).

Major traders in developing countries include commission agents, and when prices are unregulated, they do perform the role of price determination, drying, cleaning and separation of groundnuts from foreign material. They later sell to either processors or consumers. At this level, some degree of horizontal and/or vertical integration is observed. Also in most developing countries, groundnut is largely traded in domestic markets, in supermarkets and on the streets. Concerted effort should be encouraged especially to bring onboard more stakeholders to support groundnut traders and the value chain as a whole. Stakeholders including the government could largely help in promoting traders for economic empowerment by playing a basic role of securing big contracts, sharing information among traders and regulating prices. Traders as well can be trained on creating demand and business management. This would help them easily keep up with the competitive business environments.

3.4 Processing

In groundnut processing, their physical knowledge and mechanical properties like any other biomaterial is important. Aviara et al. (2013) reported that these properties hasten the designing and development of tools for planting, harvesting, handling, delivering, separating, packaging, storing, drying, oil extraction and processing. Groundnut is utilized in numerous forms; after harvesting, it can be consumed directly on farm by boiling, roasting or frying, or it can act as an ingredient in other types of food. The surplus at household level is traded as a cash crop. In companies, groundnuts can be processed into a number of products (such as oil, meal and confectionery products) for domestic and export markets. The nuts are shelled and crushed to obtain vegetable oil used for cooking. Groundnut meal which is a by-product of crushing is used as a protein supplement in livestock feeds. The confectionery products obtained include products like peanut snacks, peanut butter and cookies (Table 3.5).

Table 3.5 Products in the product group of groundnuts

Combined nomenclature number	Product
12024100	Groundnuts in shell
12024200	Shelled groundnuts
20081110	Peanut butter
20081191	Prepared or preserved groundnuts in packing larger than 1 kg net
20081196	Roasted groundnuts in packing smaller than 1 kg net
20081198	Other prepared or preserved groundnuts in packing smaller than 1 kg net

Source: CBI (2020)

3.5 Exporters

Internationally groundnut oil and meal trade has fallen significantly over the past two decades, although the trade in confectionery products has improved. Several factors are involved, and one key driving factor is *Aspergillus* contamination of groundnuts which results in aflatoxin. Most buyers have set strict tolerance limits for aflatoxin levels for food and livestock feed. Globally, India, the USA and Argentina are the major exporters of peanuts. Exports from developing countries are restricted by stringent measures put in place by regulatory bodies; therefore, developed countries take the lion share of both export and imports. To the effect, European countries control the import market for all groundnut products, although it is slowly losing market share to fast-growing Asian countries (Freeman et al. 1999). Reports indicate that <6 percent of the world groundnut crop is traded internationally, with export sales averaging to 1 billion US dollars per year (Maftei 1999). That is to say, producers do not routinely cultivate the groundnut varieties suitable for specific export market uses, such as those that can be roasted, salted or coated and those that can be converted into snacks, chocolate-based products or peanut butter.

Therefore, the key pillar of the exporter industry is the producer. This is because they select the type of variety to be grown. In real sense, various varieties are processed into different food products. For instance, the largest red-skinned Virginia varieties are used for cocktail and salted nuts, while the medium-sized Runner and the small Spanish varieties are good for oil, peanut butter and candies. Further, the Valencia variety which consists of long shells containing 3–4 kernels each are on high demand due to their capabilities of being roasted in shells (Maftei 1999). Producers as well determine the amount to be produced, and variety chosen must adapt to the demand for specific end use. The variety must have the right parameter required in the market, and the production should be higher than the local demand. For example, the kernel shape should be suitable for processing.

Just like other crops, there should be initiatives for subsidizing credit for exporters. Also government should impose strict local standards similar to those in the international markets. This would minimize chances of goods being rejected after failing to meet the global standards. On the other hand, adhering to the standards could increase their competitiveness in the international trade environments.

3.6 Consumers

Large amounts of produced groundnut are consumed locally. Although for farmers to benefit more and due to its nutritional significance, its consumption should be promoted vigorously to reach the export market. Actually, about 48 percent of the world groundnut output is used as food, whereas about 52 percent is crushed to produce oil and cake. In the USA, a fifth of the produce is exported, while 10 % is crushed for oil. Also, nearly 60 % is used directly in manufacturing food products. Argentina and South Africa generally export their groundnut products, and about 70–75% of the export is either edible or oil nuts or processed groundnut oil and cake (Maftei 1999). In Asian countries, especially Indonesia, it consumes huge amount of groundnuts as sauce and gravies. In the USA and Europe, groundnuts are most frequently used as salted, dry roasted and speciality nuts (such as hickory smoked and honey roasted), for snacks or for manufacturing of peanut butter, confectionery and chocolate-based products.

3.7 Linking Producers to Markets

Existing institutions are either formal or informal groups created by human beings that shape social expectations, interactions or behaviour (Ostrom 1990). In most groundnut-growing areas of developing nations, groundnut marketing is managed through informal institutions. That is, producers sell to traders (commission agents) who are actually paid by semi-urban-based wholesaler to purchase groundnuts. Sometimes, commission agents may operate under the rural assembler or urban market wholesalers. The latter are based in towns. The wholesalers usually have better access to price information at any given time, and therefore, they tend to fix the price while in the farm gate, and the price is very low. This causes a lot of losses to the producers. Therefore, producers operate in formal institution to benefit more. The formal institutions offer services such as contract signing and provision of forms from the governments. The formal institutional actors are officially sanctioned by formal institutional arrangements (Agrawal 2008). In many groundnut-growing countries, formal institutional actors are less. In this case, there are few local firms contracting farmers for production of groundnuts, and some are not willing to contract farmers.

To enhance the groundnut value chain, farmers should be contracted. The benefit of contracted farmers includes provision of certified seed, fertilizers and agrochemicals to support production. This type of formal arrangements can cut the reliance on imports and ensure the production chain remains steady. This would promise local farmers guaranteed markets and higher as well as predictable prices. This is because the prices offered in a formal institution are based on the world markets. Further, in a formal institution, the firm can also train farmers on good crop husbandry.

4 Conclusion and Prospects

Value chain mapping facilitated a clear understanding of the roles played by every stakeholder and the sequence of activities in every stage of the value chain. For the value chain actors to achieve their goals, proper networking in the value chain should be allowed, and this should foster synergistic actions among the stakeholders in order to cope with various challenges. This chapter therefore offered an unusual opportunity of improving on every stakeholder by revealing what each stakeholder is supposed to do.

5 Recommendations

The chapter recommends that the capacity of value chain actors should be built basing on the roles in every stage. Furthermore, policy formulations such as developing national and regional groundnut sectoral and seed strategies should be embraced to improve the groundnut value chain.

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Chapter 4
Aluminum Uptake, Callose Accumulation, and Invertase Activity in Lowland and Upland Rice Genotypes in Relation to Aluminum Stress Tolerance

Poonam Pandey and R. S. Dubey

Abstract Aluminum is among the prominent restricting factor accountable for the growth of plants in acidic soils pertaining to its solubility. The absorption of aluminum (Al^{3+}) by rice roots was examined in this work using seedlings from two cultivars (tolerant and sensitive) treated with $AlCl_3$ (1 mM) in fresh sand culture. The progression of Al through the roots was seen using hematoxylin and Eriochrome cyanine R staining. When compared to the sensitive cultivar, the tolerant cultivar has a reduced Al absorption rate. It shows the presence of some extrinsic mechanisms that control the tolerant rice cultivar's behavior. The increase in Evans blue absorption after Al^{3+} treatment indicated root cell injury, with more apparent uptake in sensitive cultivars than tolerant cultivars. Aluminum fluorescence intensity increased with Morin staining in sensitive than tolerant cultivars, according to confocal microscopy. The results presented here confirmed that the increased accumulation of Al^{3+} leads to reduced rice seedlings growth and increased invertase activity, callose accumulation, and cell death. It also indicates that metabolic procedures and the transduction of the signals contributing to increased invertase movement help the tolerant variety maintain higher root development in harmful Al^{3+} concentrations.

Keywords Aluminum toxicity · Al localization · Confocal · Rice (*Oryza sativa* L.)

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_4

1 Introduction

One of the foremost contributors and constraints contributing to crop growth in acidic soils is aluminum (Al) phytotoxicity that accounts for 40 % of arable land (Sade et al. 2016). This phytotoxicity is found to be released in big quantities at low pH (pH 5.0 or less). This led to damage to overall root structure, growth, and thus yield. Al has a complex chemical structure as well as biological activities (Kochian et al. 2005). The pH scale of the soil determines the Al that is available in the soil. The structure is octahedral hexahydrate, Al $(H_2O)_6^{3+}$, at low pH (about 4.3), and is sometimes abbreviated as Al^3. The problem of Al^{3+} toxicity is multifarious through soil acidification caused due to inconsistent usage of ammonia as well as fertilizers constituting amides. Nitrogen fixation in legumes, an imbalance between nitrogen and sulfur (Guo et al. 2010), and absorption of excess cations and anions also contribute to this acidification. Al is not just phytotoxic but inhibits plant growth too. Besides, it also harms human health because it is passed down the food chain from animals to people (Jaishankar et al. 2014). The key indication of toxicity caused by Al is suppression in the growth of the roots that usually happens as soon as 1 or 2 h after Al exposure (Horst et al. 2010). This root growth suppression results in a thin, thickened, diminished, and uneven root system (Ciamporova 2002). The variants that are Al sensitive tend to gather additional Al within the root tissue than Al tolerant. For example, Al-sensitive cultivars like maize, rice, wheat, and soybean displayed more Al contents in their root tips than the resistant version (Du et al. 2010; Kang et al. 2011; Matonyei et al. 2014; Garcia-Oliveira et al. 2016).

The progression and build-up of the Al in the root tissues could be measured using a variety of methods. The employment of Al-specific dyes is one of them. This build-up is required to be investigated for which staining techniques are often quick and easy. One of the most common methods is the comparison of the length and weight of the roots of the plants affected with or without Al. Nonetheless, this method is not ideal for the large population as there are significant variations in root length, and this process takes time also. Because of these drawbacks, a quick method, *staining with hematoxylin*, was discovered that utilizes the coloring formation when the Al-induced root with the stain (Polle et al. 1978). A few researchers have used this method to screen Al resistance phenotypes in various crop species, such as maize (Lidon et al. 2007), pea (Singh et al. 2009), and chickpea (Singh and Chaturvedi 2007). Another method, *staining with Eriochrome cyanine R*, enables the visualization of the Al across the root. In this, the roots damaged because of Al were deeply stained (pink) despite non-damaged roots remaining unstained (white). This method is suitable for assessing large numbers of plants at the same time. *Evans blue staining* is considered as an index of damages caused by plasma membranes and programmed cell death in plants (Yamamoto et al. 2001). Minute concentrations of Al could be identified using fluorophores like Morin using fluorescence microscopy (Eticha and Horst 2005). The detection limit has been identified as 2×10^{-9} M. (Lian et al. 2003).

Along with the inhibition of Al-induced growth of the root, the induction of callose formation was observed in several plant species as a physiological pointer to the Al sensitivity (Jones et al. 2006). Different stressors are identified as the triggering agent for callose synthesis whose in-depth methodology is unknown but compromises the plasma membrane's integrity and function (Chen and Kim 2009). In biotic and abiotic stress conditions, an increase in cytosolic calcium (Ca^{2+}) activity synthesizes the β-D-glucan in plants (Bhuja et al. 2004). Al also causes a transient upsurge in cytosolic Ca^{2+}, according to Bhalerao and Prabhu (2013).

In abundance, metals such as Cd^{2+}, Ni^{2+}, Al^{3+}, and As^{3+} induce toxicity in growing plants and also influence the activity behavior of various carbohydrate metabolism-related enzymes (Verma and Dubey 2001; Mishra and Dubey 2013; Jha and Dubey 2004; Mishra and Dubey 2008; Abbas et al. 2018). The main photosynthetic end products are starch and sugar, and their levels inside plants give important plant production information. Under diverse stress conditions, starch and sugar storage, translocation, and metabolism are all impacted. The metabolism of sucrose is critical for energy production and plant growth under stressful conditions (Harada et al. 2005). Invertases are found in enzymes that regulate the sucrose content in plants in acidic, alkaline, and neutral forms (Tauzin and Giardina 2014). Sucrose-aided root cell division, elongation, and expansion. As a result, Al^{3+}-induced changes in invertase activity are probably part of a cell-wall-based toxicity resistance mechanism to aluminum. The most Al-resistant cereal crop is rice which uses several methods to achieve high Al resistance. Little is known on the mechanism of increase in Al tolerance in rice (Famoso et al. 2010). It promoted us to use rice as a model plant to examine the mechanism of Al tolerance.

To explore this phenomenon in detail, two rice cultivars have been used, namely, Malviya-36 as the Al-sensitive one and Vandana as the Al-tolerant one. It has been observed that distinct Al^{3+} concentration in roots generally leads to varying tolerance levels, and thus, invertase activity and callose accumulation have been examined as disclosed by Morin stain.

The selection of appropriate cultivars is essential for the study of tolerance mechanisms. For this, the sensitivity and tolerance mechanism of both cultivars was confirmed using *Eriochrome cyanine R staining*. Al uptake in roots is seen by *hematoxylin staining* in different cultivars to separate the degree of participation for exploring the tolerance mechanism at the external as well as internal levels.

2 Materials and Methods

2.1 Plant Material and Treatment Levels

Malviya-36 and Vandana are the two variants of Indica rice (*Oryza sativa* L.) cvs. seeds that are used for conducting the experimental work. After a 24-hour inhibition in water, seeds are wet with 0.5 mM $CaCl_2$ solution and kept at 28±1°C with 80 %

relative humidity in the BOD incubator cum humidity (York Scientific Industries, New Delhi, India) for 5 days. Seedlings subsequently were elevated in purified quartz sea sand, and Yoshida nutrient solution is used for the next 10 days for saturation (Yoshida et al. 1976). Further, the uprooted seedlings were treated with $AlCl_3$ (1mM) for the next 2 days in the presence of fresh and sand cultures.

2.2 The Impact of Morin Staining in the Localization of Al in Roots

Morin staining as defined by Tice et al. (1992) has been utilized in the current work. The roots were initially washed for 10 min in the presence of a buffer, NH_4OAc having a pH of 5.5, followed by staining by 100 μM for 1 hour in the same buffer. Till the elution of the stains, washing will be continued. The lateral segments of the roots were cut and then observed through a microscope coupled with fluorescence at an excitation and an emission wavelength of 420 and 510 nm, respectively, until it fluoresced green.

2.3 Hematoxylin Staining in the Detection of the Accumulated Al in Root Tips

Hematoxylin staining (Ownby 1993) has been utilized for visualizing the deposition of the Al in the roots of sensitive as well as tolerant variants of the cultivars. The roots were initially washed for 15 min followed by staining at room temperature. Staining is done using a solution of 0.2% hematoxylin (w/v) and 0.02% KIO_3 (w/v). Further, distilled water is used for washing it for 15 min, and then photographs were taken. A spectrophotometer (Bausch and Lomb, Spectronic 20, USA) was utilized for quantifying the optical density of the stains at 490 nm on 15 root tips of 5 mm each after 1ml of 1 M HCL treatment for 1 hour.

2.4 Determination of Loss of Plasma Membrane Integrity

The loss of integrity of the plasma membranes has been determined using the modified Evans blue staining method as defined by Schützendübel et al. (2001). The staining of the seedlings was conducted for half an hour with a 0.25% (w/v) aqueous solution. The washed cross-sectional root tips with distilled water were utilized for viewing through the light microscope. To determined Evans Blue Uptake, stained cross-sections roots of 10 mm length were homogenized in 1 ml of 1% (w/v) aqueous sodium dodecyl sulfate (SDS) followed by centrifugation at

13,500 × g for 10 min at room temperature. Measure the optical density of the supernatant spectrophotometrically at 600 nm.

2.5 Eriochrome Cyanine R Staining

To confirm the sensitivity and tolerance of selected rice cultivars toward Al toxicity, Eriochrome cyanine R staining was used (Aniol 1995). Seedlings were removed and placed in distilled water for 30 min after 48 h of Al treatment. One-tenth of an aqueous solution of Eriochrome cyanine R was used to stain the roots for 10 min. The surplus dye was detached by several washes with distilled water, and then photographs were taken with a high-resolution camera.

2.6 Histochemical Detection of Callose in Root Tissues

The Al^{3+}-induced callose accumulation detection has been conducted using aniline blue staining in the current work. The roots are secured for 1 h using 10% ethanol (FAA) and formaldehyde and 5 % glacial acetic acid. The top 1 cm root tip was cut and cleaned using de-ionized water and stained for 10 min (Kauss 1992). One-tenth of water-soluble aniline blue is applied to 50 mM glycine-NaOH buffer with a pH of 9.5 and then explored using a fluorescence microscope.

2.7 Measurement of Callose Content

The calculation of callose content has been done according to Bhuja et al. (2004). A total of 25 root segments were taken and washed in ethanol for 30 min followed by homogenization in 1M NaOH. The samples were incubated at 80 °C for 20 min and further centrifuged at 12,000 × g for 5 min. The resultant was further treated to the following combination.

- 50 μl of supernatant along with 100 μl of 0.1% aniline blue
- 50 μl of 1M HCl
- 150 μl of glycine-NaOH buffer pH 9.5

Afterward, incubation for 20 min at 50 °Cand 30 min at room temperature fluorescence signal recorded using excitation at 380 nm (filter 530/20) and detection of fluorescence at 485 nm (filter 485/20).

2.8 Analysis of Invertase Activity

A total of six seedlings of each Al^{3+} exposed cultivar is incubated for 3 h to detect invertase activity. These seedlings were treated to a neutral reaction medium buffer at room temperature; after which, photographs were captured using Olympus light microscope. The buffers (Doehlert and Felker 1987; Zrenner et al. 1995) consisted of the following solutions:

- 0.38 mM sodium phosphate with pH of 7.5
- 0.024% tetrazolium blue
- 0.014% phenazine metosulfate
- 30 U of glucose oxidase
- 30 mM of sucrose
- For control, incubation medium without sucrose and Glucose oxidase

2.9 Statistical Analysis

The experimentations were repeated thrice, and the data was used as the mean of the standard deviation of the obtained replicates. Analysis of variance (ANOVA) is used for obtaining the mean difference of the control and treatment groups. The significance of this difference is represented as * for $p \leq 0.05$ and ** for $p \leq 0.01$. Further, Tukey's multiple range test has been used.

3 Results

3.1 The Impact of Morin Staining in the Localization of Al in Roots

Morin (3,5,7,2′,4′-pentahydroxyflavone) is an Al-specific fluorescent dye that constitutes a fluorescent complex when combined with Al. The greater the Al accumulation, the brighter the fluorescent light. An intense green Morin fluorescence was seen in the root section, whereas there was almost little fluorescence in control (–Al) plants (Fig. 4.1). It was observed that low fluorescence was found in roots stained with Morin that was unexposed to Al and whatever fluorescence was seen was confined to the epidermal surface. When compared to sensitive roots, tolerant cultivar root cross-sections revealed significantly less Morin staining.

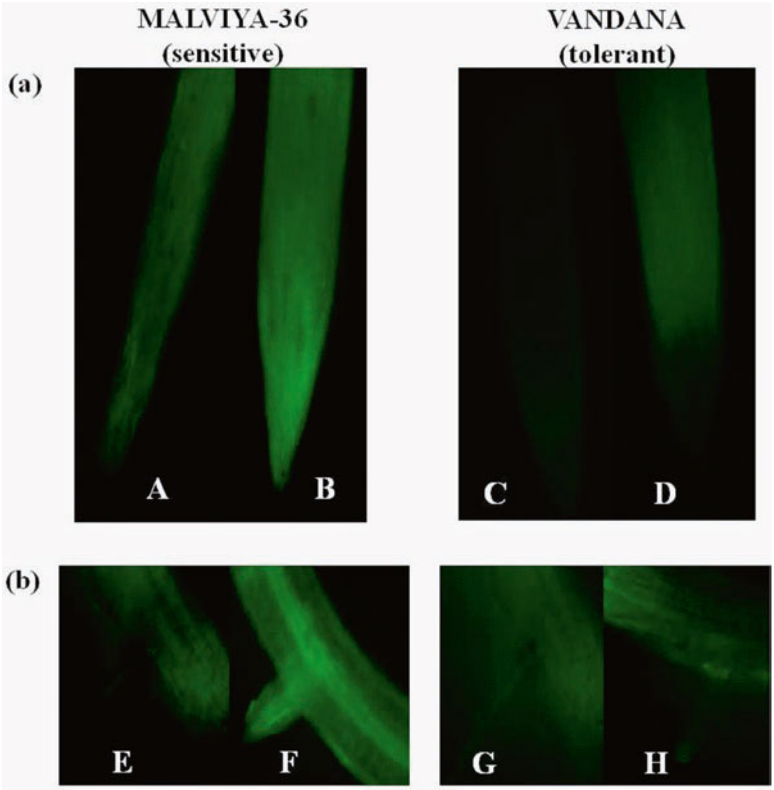

Fig. 4.1 (**a**) Fluorescence detection of Al in rice root tips after Morin (100 μM) staining in roots of Malviya-36 and Vandana seedlings. The Seedlings were grown for 10 days and then uprooted followed by treatment either in Yoshida nutrient solution (control, without Al^{3+}, denoted as *A, C*) or in nutrient solutions containing 1mM Al^{3+} (*B*, *D*) for 48 h. **(b)** The lateral roots of the seedlings obtained from matured segments of the primary roots

3.2 Determination of Aluminum Uptake

A hematoxylin stain was utilized to investigate the uptake of Al in the seedlings' roots. When the roots of cvs. Malviya-36 and Vandana seedlings are stained with the Al-specific dye hematoxylin, it is detected that the roots of Al-treated seedlings of Malviya-36 take up a greater amount of stain than tolerant cv. Vandana (Fig. 4.2). Though there was no reaction with Al^{3+}, the hematoxylin stain was absorbed by control roots, and thus dull redness is visible. Spectrophotometric analyses revealed that dye uptake was increased by four- and twofold in roots of 1mM Al^{3+}-treated seedlings in cv. Malviya-36 and cv. Vandana, respectively, as compared to controls.

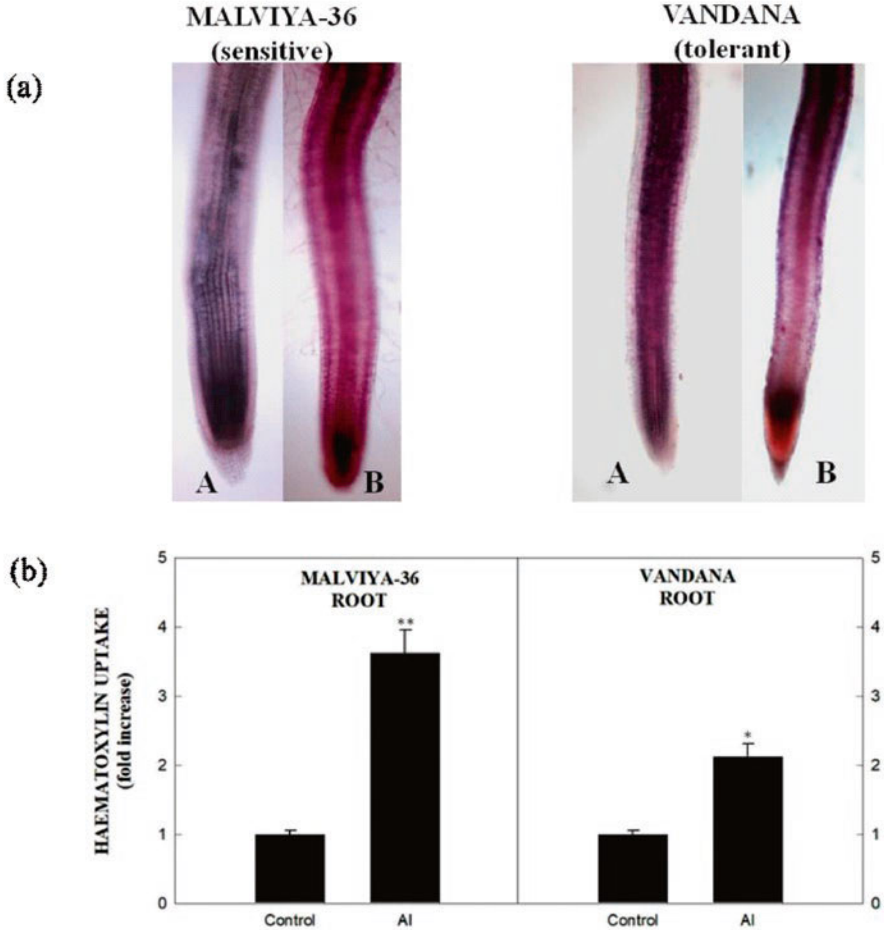

Fig. 4.2 **(a)** Microscopic view of hematoxylin-stained roots of Malviya-36 and Vandana seedlings. The seedlings were grown in sand cultures for 10 days followed by its treatment in either Yoshida nutrient solution (control, without Al^{3+}, denoted as *A*) or in nutrient solutions containing 1mM Al^{3+} (*B*) for 48 h. **(b)** The exposure of hematoxylin staining resulted in the accumulation of Al in root tips (5 mm). The resultant value after three independent values is mean ± SD (standard deviation depicted by bars). As per Turkey's test, * and ** depict the differences as per controls at $p \leq 0.05$ and $p \leq 0.01$, respectively

3.3 The Damage in a Membrane Formed Due to Al in Root Tips

Evans blue has been utilized as a marker for cell death as well as for identifying the loss in the integrity of the plasma membrane. An increase of Evans blue absorption was detected in comparison to controls for Al-treated rice seedlings. Evans blue stain uptake increased significantly ($p \leq 0.01$) in the roots of both rice cultivars as the concentration of Al^{3+} treatment increased, with notably higher uptake in the Al sensitive cultivar than the tolerant cultivar (Fig. 4.3). Even in controls, the stain taken by roots of cv. Malviya-36 seedlings were higher than cv. Vandana. The findings make a strong point regarding the increased permeability of the plasma membranes after treating them with Al.

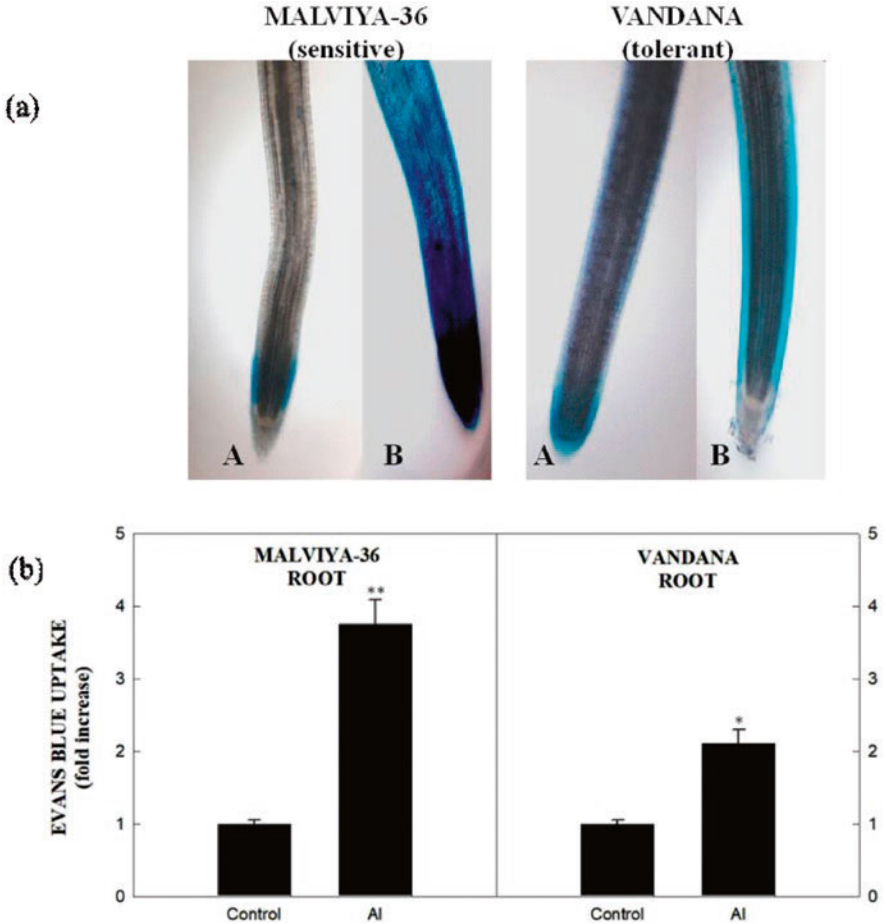

Fig. 4.3 **(a)** Representation of loss of plasma membrane in root tips of Malviya-36 and Vandana seedlings through histochemical detection. The seedlings were grown in sand cultures for 10 days followed by its treatment in either Yoshida nutrient solution (control, without Al^{3+}, denoted as *A*) or in nutrient solutions containing 1mM Al^{3+} (*B*) > for 48 h. **(b)** The loss of plasma membrane integrity after exposure of dye Evans's blue is depicted. The resultant value after three independent values is mean ± SD (standard deviation depicted by bars). As per Turkey's test, * and ** depict the differences as per controls at $p \leq 0.05$ and $p \leq 0.01$, respectively

3.4 Eriochrome Cyanine R Staining

When cultivars were kept for 12 days with or without nutrient solution constituting 1mM $AlCl_3$ in the growth medium followed by staining with Eriochrome cyanine R; depicted that the stain taken up by roots of treated seedlings of Malviya-36 was substantially greater than that of Vandana (Fig. 4.4). Control grown seedlings of any cultivar show no stain in their roots.

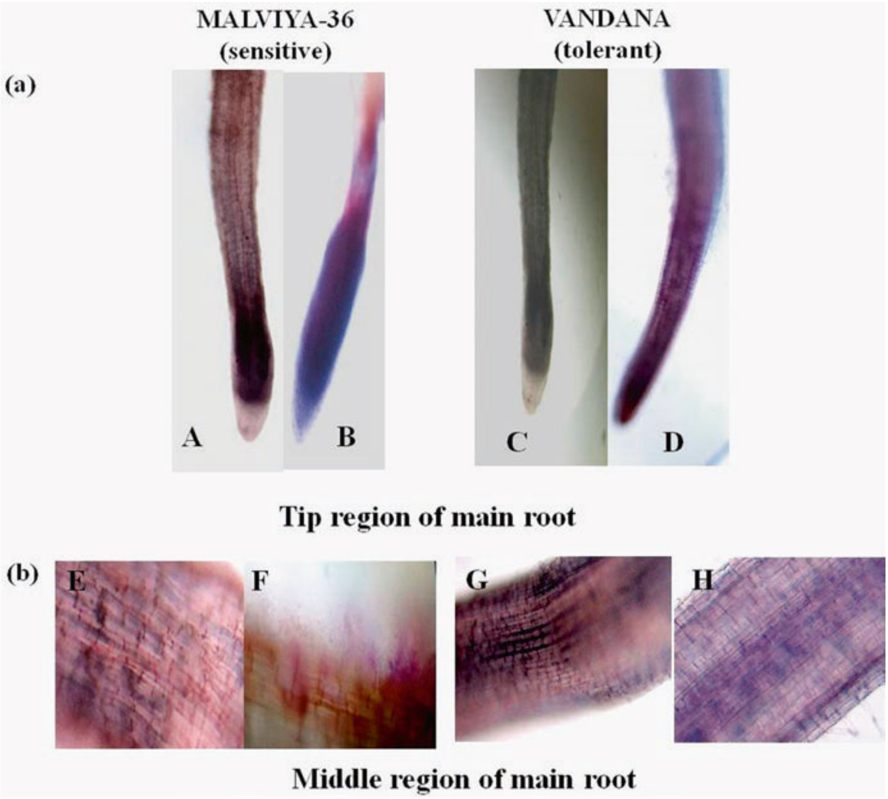

Fig. 4.4 Pictures showing **(a)** tip regions and **(b)** middle regions of main roots after Eriochrome cyanine R staining in Malviya-36 and Vandana seedlings. The seedlings were grown in sand cultures for 10 days followed by its treatment in either Yoshida nutrient solution (control, without Al^{3+}, denoted as *A*, *C*, *E*, *G*) or in nutrient solutions containing 1mM Al^{3+} (*B*, *D*, *F*, *H*). > for 48 h

3.5 Callose Accumulation

The production of callose has been regarded as a measure for determining the level of Al damage to the treated plants. Aniline blue staining and fluorescence microscopy are used to visualize callose formation. Callose exhibited bright green-yellowish spots under the fluorescence microscope, whereas the initial fluorescence observed was vivid blue (Fig. 4.5). The sensitive type root tips that had not been treated fluoresced faintly, and those exposed to Al fluoresced brightly, indicating

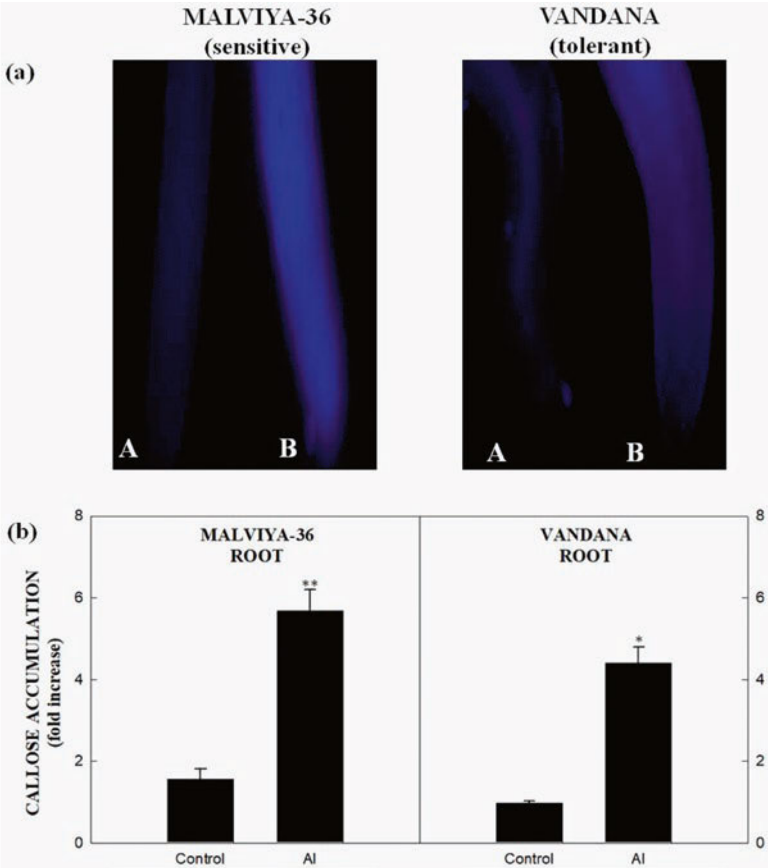

Fig. 4.5 **(a)** The representation of callose localization on exposure of aniline blue staining in root tips of Malviya-36 and Vandana seedlings. Seedlings were grown in sand cultures for 10 days followed by its treatment in either Yoshida nutrient solution (control, without Al^{3+}, denoted as *A*) or nutrient solutions containing 1mM Al^{3+} (*B*) for 48 h. **(b)** The quantification of the root tips grown after control and the seedlings after treatment with Aniline blue stained was recoded. The resultant value after three independent values is mean ± SD (standard deviation depicted by bars). As per Turkey's test, * and ** depict the differences as per controls at $p \leq 0.05$ and $p \leq 0.01$, respectively

callose accumulation. In the presence of Al, callose accumulation in the tolerance cultivar decreased considerably to levels somewhat higher than those reported in the untreated controls, compared to the sensitive variety. When dye uptake for callose accumulation was compared to the control in roots of 1mM, Al^{3+}-treated seedlings, dye uptake for callose accumulation was increased by 5.7- and 4 fold in cv. Malviya-36 and cv. Vandana, respectively, implying callose induction to be an early and robust Al stress indicator.

3.6 Invertase Activity Assay

Tolerant roots (Vandana) exhibited strong activity (cellular divisions in the basal part and more noticeable in the apex) and invertase expression after its exposure to 1mM $AlCl_3$ for 2 days (Fig. 4.6). When compared to tolerant roots (Malviya-36), invertase activity was lower in sensitive roots (Malviya-36) (Fig. 4.6).

4 Discussion

For a long time, aluminum has been regarded as one of the key problems restricting agricultural output around the world. A major portion of the arable land across the world is acidic with significant Al toxicity. A vast area of such land lies in developing countries. Al was, therefore, a potential threat to these countries' development. It is imperative to choose and breed crops for Al resistance to a fast, reliable screening system to discriminate between sensitive and tolerant genotypes. Plants have built up a few techniques to deal with Al toxicity. Organic acid exudation was first detected as helping to protect snap beans against Al toxicity (Miyasaka et al. 1991). It was found that the cultivars that are Al resistant emit almost eightfold citrate than the sensitive ones in a long run. Despite several attempts in past, most of the works could not justify the tolerance of rice to Al toxicity. Another notion of rice resistance was cell wall polysaccharides (Yang et al. 2008). As a result, it's critical to understand its molecular and genetic mechanisms for Al tolerance.

The toxic symptoms of Al^{3+}-treated roots in our research were essentially the same as those previously discovered (Alvarez et al. 2012). Sivaguru and Horst (1998) have reported the distal region to be more Al sensitive in the root apex. As a result, root length is the most reliable metric for determining Al^{3+} toxicity tolerance and sensitivity. In the present study, Al^{3+} inhibited root growth in both rice cultivars, with Malviya-36 being significantly more pronounced than Vandana. The use of a fluorochrome such as Morin (2,3,4,5,7-pentahydroxyflavone), which forms a fluorescent complex with aluminum (Al) (Eticha et al. 2005) and thus used for the detection of Al at the outside of roots with significant differences among cultivars, is the simplest and widely used method for Al localization. At low pH, it is found to be selective to Al and has a detection limit of 2 nM in vitro (Lian et al. 2003). Al^{3+}

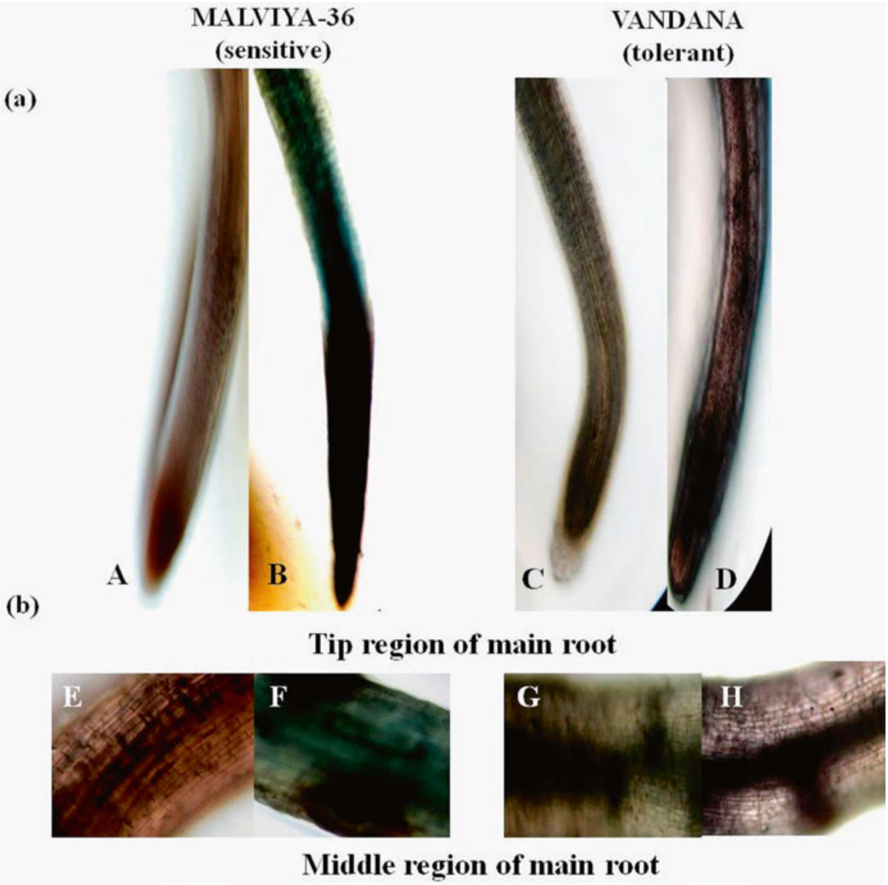

Fig. 4.6 **(a)** Tip regions and **(b)** middle regions of primary roots showing invertase activity staining patterns in Malviya-36 and Vandana seedlings. The seedlings were grown in sand cultures for 10 days followed by its treatment in either Yoshida nutrient solution (control, without Al^{3+}, denoted as *A*, *C*, *E*, *G*) or in nutrient solutions containing 1mM Al^{3+} (*B*, *D*, *F*, *H*). > for 48 h

works as a mordant in hematoxylin staining, binding to oxidized hematoxylin (hematein) and forming a colorful complex between hematoxylin and root-bound Al (Polle et al. 1978). In comparison to cv. Malviya-36, hematoxylin staining revealed decreased uptake of the Al by roots than that of Vandana seedlings. It was also found that Al content is more in the roots of Malviya-36 than that of Vandana. It was also observed that the Al content amplified with rise in the concentration of Al treatment as well as its exposure. Vandana's roots absorb less Al, indicating that this cultivar benefits from an external resistance mechanism. Alike outcomes were conveyed for hematoxylin staining in rice (Pandey et al. 2015; Rosello et al. 2015), wheat (Shao et al. 2015), and chickpea (Sharma et al. 2015). The damage in the Al-induced membrane as observed using Evans's blue could be attributed to prolonged exposure that resulted in mechanical disturbance of cells in the elongation zone. More exposure of these stains by roots of Al^{3+}-treated saplings of sensitive cv. Malviya-36 suggests more damage and cell death in this cultivar than similarly stressed seedlings of tolerant cv. Vandana. In the roots of cv. Malviya-36, cell death paralleled with high Al-induced ROS production and severe oxidative stress which indicates that cell demise happened because of the damage caused by overproduced ROS in cells by Al^{3+} stress. According to Pan et al. (2001), increased ROS production could result in cell death, and higher Al concentrations could cause root cell necrosis. Even with modest Al toxicity treatment, a considerable increase in Evans blue dye absorption was observed in the prior study (Pandey et al. 2015). Similar findings have been found in maize (Wang et al. 2015), tobacco (Sivaguru et al. 2005), Melaleuca tree (Tahara et al. 2008), pea (Motoda et al. 2011), and wheat (Motoda et al. 2011). (Aggarwala et al. 2015). Evans blue uptake by roots of barley seedlings was also seen by Zelinová et al. (2011), even at low Al concentrations that did not hinder root growth. Al absorption and cell death in root tips are not only a substantial result of Al-induced oxidative stress, but they also serve as one of the Al tolerance mechanisms (Giannakoula et al. 2010). Current work incorporates Eriochrome cyanine R for classifying Al sensitivity and rice cultivar tolerance by showing a much higher stain uptake in roots of Al^{3+}-treated seedlings of cv. Malviya-36 than cv. Vandana. The root section formed following Al treatment was white (unstained) when Al treatment did not harm the root apical meristem, whereas roots impacted by Al treatment were intensely pink stained (Aniol 1995). This method takes only 10 min to stain and was appropriate for assessing large numbers of plants at once. This rapid staining method has been used to screen Al tolerance in wheat, barley, and rye cultivars (Wang et al. 2006; Ma et al. 2004; de Sousa et al. 2016).

Aluminum-induced callose seems to be a physiological marker for Al-induced injury. Callose builds up in the cell wall around plasmodesmata in response to the Al damage within the roots. Increased Al concentration from 0 to 100 mM could result in an enlarged accumulation of callose (Larsen et al. 1996). The lack of callose deposition suggests that there are more primary mechanisms of Al^{3+} resistance that could activate sooner than callose synthesis.

Thus, callose deposition could not be attributed as a primary resource for averting Al^{3+} penetration. Though studies reported (Sivaguru et al. 2000; Wissemeier and Horst 1995) callose to be a cell-to-cell inhibitor and Al-induced callose formation in some cultivars root tips, the current study has found callose formation in newly root tips of higher Al concentration. Increased Al tolerance is linked to lower callose formation and lower oxidative stress in transgenic plants. Callose deposition and accumulation especially in aluminum-sensitive cultivars reflect physiological stress and the degree of cumulative cell damage.

The generation of hexoses is maximized by cell wall and vacuolar invertases, which enhance cell respiration, division, and growth (Koch 2004). When compared to Malviya-36, Vandana roots have more invertase activity, which could indicate alterations in primary metabolism and root cell proliferation, as well as a resistance mechanism.

Past studies revealed that increased sucrose activity in rice could lead to hexose accumulation under Al toxicity. Simon et al. (1994) observed reduced invertase acid activity under Al^{3+}. Similar observations were made where increase invertase activity has been observed under arsenic, Al, and Cd toxicity (Verma and Dubey 2001; Jha and Dubey 2004; Shahnawaz et al. 2017) and salinity and cold stress (Mishra and Dubey 2008; Livingston and Hensen 1998).

The current results demonstrated better and improved discriminating Al susceptibility in variants of cultivars using several staining techniques. Thus, the hypothesis taken has confirmed that high Al concentration results in reduced growth and callose accumulation, associated with invertase activity and cell deaths. It is clear that improvised root growth at toxic Al^{3+} concentrations is accompanied by increased invertase activity, and thus better understanding of expression and activities in root regions could be made at apoplastic and symplastic root regions.

Acknowledgments The first author is obliged to the University Grants Commission (UGC) for providing Fellowship to conduct this work.

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Chapter 5
Gender Issues in Farming: Challenging Socially Embedded Positions in Agrarian Context

Uma Sah, Kushagra Joshi, and Shantanu Kumar Dubey

Abstract Gender role and their relative participation in agriculture vary considerably across households, communities, regions and countries. These roles are recognized as the determining factors of distributing the resources and responsibilities between men and women. In developing countries women are accounting for above 400 million constituting approx. 43% of all labour force engaged in farming. Categorically, sub-Saharan Africa engages 60% of women in agriculture. In South Asia this proportion stands about 70%. Empirical evidences across the world have also reflected that rural women are important productive workforce extensively involved in agricultural activities. The International Labour Organization has estimated that globally employment of men and women in agriculture as a percent of total employment has witnessed the declining trend from 44.4 and 42.6% in 1991 to 27.7 and 25.3% in 2019, respectively. This chapter attempts to highlight how the differential gender roles are influencing the natural resource management, crop husbandry and livestock raising, what are the different issues coming forth as the barriers of engendering the development paradigms and what could be the best possible intervention mechanisms for mainstreaming both the genders in different planned initiatives.

Keywords Gender · Engendering · Farming · Issues · Strategies

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_5

1 Gender: A Social Construct

Gender has socially and culturally defined meanings associated with both men and women. Different roles have been ascribed socially to men and women to perform. This applies to reproductive, productive and community roles as well. Gender is a social construct (Schneider et al. 2005) and is a structural feature of a society, built upon the binary divide between men and women. Gender systems are complex, multidimensional and diverse within culture and across culture (Mason and Smith 2003).

Gender dynamics represent a key element of the food production systems and a determinant of their outcomes as well as a nested set of perceived yet practiced inequalities. In traditional rural societies, the tasks are distributed among men and women on basis of socially approved gender roles. These gender roles are though dynamic in nature that may change with time and socio-economic, cultural and religious contexts. FAO (2010b) also confirmed gender roles as the determining factors of distributing the resources and responsibilities between them. Many a times the approved gender roles tend to favour a particular social component at the cost of the other, the reason for which is again based on the local contexts. These contexts are usually biased against the women, which hamper their productivity and efficiency despite their higher contribution in any economic activity.

2 Gender Roles in Agriculture

Gender role and their relative participation in agriculture vary considerably across households, communities, regions and countries. However, men are usually seen performing the task requiring more of physical strength like land preparation, ploughing, driving draught animals, irrigation, etc., while women perform task like sowing, weeding, harvesting and storage. In production situations that involve highly mechanized large-scale cash cropping, men tend to perform larger role, while women are more involved in small-scale cultivation of cash crops and are involved in producing food crops for household consumption, which is commonly undervalued compared to other forms of agriculture. In contrast, Adétonah et al. (2015) reported active involvement of women in land clearing, tillage, harvesting, threshing and marketing of staple food crops in Benin and Mali.

In developing countries women are estimated to account for above 400 million which constitute approx. 43% of all labour force of developing countries who are engaged in farming (UN Women 2012). Categorically, sub-Saharan Africa engages 60% of women in agriculture. In South Asia this proportion stands about 70%. Empirical evidences across the world have also reflected that rural women are important productive workforce that are extensively involved in agricultural activities (Prasad et al. 1988; Shiva 1991; Dimri 1999; Sah 1999; Fabiyi et al. 2007; Adétonah et al. 2015, Nahusenay and Tesfaye 2015). As per the released estimates

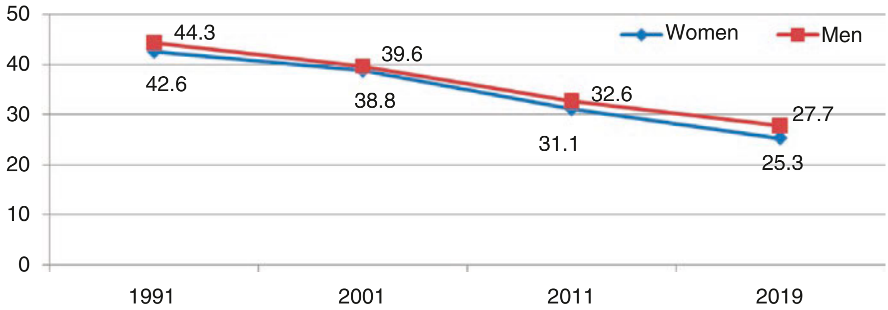

Fig. 5.1 Globally changing patterns of gender employment in agriculture as percentage of employment (ILO estimate)

of the International Labour Organization, globally employment of men and women in agriculture as a percent of total employment is following a declining trend from 44.4 and 42.6% in 1991 to 27.7 and 25.3% in 2019, respectively (Fig. 5.1).

In developing countries including India, women are responsible for both reproductive and productive roles contributing very effectively (33% of the agricultural labour force and 48% of self-employed farmers) in nation's economy. Specifically, dairying and animal husbandry is one such sector in which women outnumber the men, making this sector by and large dependent on the women workforce. Considering the work of women directly or indirectly in different activities like agricultural labour, working in the family farm, dairying and animal husbandry, etc., they may be treated as the actual farmers despite their seasonal, intermittent and uncertain work pattern. The declining trend of women participation in agricultural activities in India is evident as per census data, which confirm that the share of total women workers in agriculture was recorded to decline from 71.8% in 2001 to 65% in 2011. On the contrary, the share of women in total agricultural workers recorded a decline from 39% in 2001 to about 37% in 2011. Similarly, the number of women cultivators has also come down from 41.9 % in 2001 to 36% in 2011.

Case Study: Women in Pulse Production System (Sah et al. 2014)

In pulse production operations, participation of women farmers was highest in seed cleaning (61%), weeding (45%) and land cleaning (45%) as sole contributor. Harvesting was another activity where women are solely involved to a great extent of about 41% of the rural households. In contrast, male farmers contributed more in the operations like preparing the field (72%), arranging and maintaining the irrigation channels (50%) and applying fertilizer (49%) as sole participant. Participation of farm women in all the post-harvesting-related activities of pulse crops, either solely or jointly with their male

(continued)

counterparts, was seen to be high except for marketing. However, there were several activities after production also, namely, cleaning and sorting of grains (93%), winnowing (67%), value addition (89%) and processing of pulses (85%) that were solely performed by women. Likewise, drying of harvested produce (53%), bundling them and transporting (42%) them to stores were performed exclusively by women, however some time jointly also. Marketing of farm produce was one such area which was solely done by male farmers (81%), while in 19% cases, it was carried out jointly. The activity of storage of pulses was jointly performed by farmers and farm women in about 44% of the households (44.4%). Thus, distinct gender-differentiated role existed within the households with reference to pulse production as well as post-harvest operations. The major challenges perceived by farm women were directly related to activities wherein they had higher involvement like storage and related post-harvest handling operations, sowing and seed preparation, etc.

Case Study: Gendered Participation in Millet Production System (Jeeva et al. 2019)

Disaggregating the participation of male and female millet farmers easily identified the barriers and bottlenecks resulting from gender-based discrimination as done for Odisha, an Eastern State of India. The major activities like selecting the suitable variety to grow (60%), preparing the land (65%), seed management (80%), manuring (75%), irrigation (75%), intercultural operations and weeding (80%) and harvesting (80%) were performed by the women only. Besides, they also contributed immensely in curing and drying (80%), threshing (95%), winnowing (95%), storage management (90%), transportation (60%) and marketing (70%). Every seven in ten sellers were farm women engaged in selling the produce either from farm gate to consumers or via middlemen. However, Southern Indian states like Karnataka and Tamil Nadu were exception to it as the women participated to medium or lower extent in finger millet production. However, women contributed for seed management, weeding, harvesting, cleaning and drying the grain (70–75%). As the decisions on when, where and how much to sell were mostly taken by men, women participated to lesser extent in marketing of the produce (25–30%).

Both the case studies confirm the gender-based division of labour in different social and production situations in India. It further envisages that men and women often manage, use and control natural and agricultural resources differently; their roles, rights and responsibilities differ according to geographic and cultural context. Understanding such differences and associated gendered power relations shall ensure greater equity and efficiency in agricultural programmes and policies. Farming is an economic activity involving several allied sectors as a whole; therefore, mainstreaming the gender in agriculture requires identifying gender-based issues and identifying pathways to provide equitable opportunities to both the genders, thus making the farming productive as well as sustainable.

2.1 Gender and Natural Resource Management

Women and men play different roles in natural resource management and conservation of the environment. Whereas women utilize the natural resources for sustaining the livelihood, men tend to exploit them for commercial purposes (Mawaya and Kalindekafe 2007). Women also play crucial role in management of natural resources and nurturing these life support systems. Though women are natural resource managers at local level, their participation in decision-making process at intra-household or inter-household levels is limited. Their traditional role of collecting fuel wood, fetching water and obtaining fodder places them close to the natural resources. In western hills of India, collection of fodder from nearby forest or fields is a frequent household activity, and almost one female from every household visits forests once or even twice a day for this purpose (Dhyani and Maikhuri 2012). Women trek for longer hours and distances, using more energy, to ensure family sustenance. The activities like water collection and purification, hygiene, health and safety increase women's workload.

Thus, in developing countries gathering of household fuel is primarily done by women who also travel further and work harder when fuel wood or charcoal becomes scarce (WEDO 2003). With the specific case of Ethiopia (Abate 2020), empirical evidence indicates women to be the natural resource managers and primary collectors of fodder and fuelwood(76%), fetchers of water (71%), and active workers in agriculture (83%).

Women are the conservers of biodiversity. They are custodians of seeds and are actively involved in its selection, multiplication and management. Among the local communities in the Himalayan mountain regions, the traditional seed management and exchange systems (80–90%) meet the seed requirements of all farm-household crops, wherein again the role of women is very significant (Kerkhoff and Sharma 2006). As the traditional knowledge related to seeds is possessed by women who are also the custodians of diverse genetic resource pool, thereby enabling their in situ conservation (Shrestha et al. 2010) will help in strengthening their role as traditional seed managers. The case study from Nepal and Indian hills confirms that women outdo men in terms of their involvement in use and management of natural resources in sectors like water, agriculture, livestock, forestry and fishery (Upadhyay 2005). Even the great *Chipko* Movement is an immortal example of women's role as custodian of natural resource in Garhwal hills of Uttarakhand state of India by which 60–80% tree survival rate was achieved that contributed to reducing landslides and provided fuel and fodder (Joshi 1982). The movement demonstrated how women could make the difference in protecting forests and developing afforestation projects.

Another instance to quote is the save our seeds movement, or *Beej Bachao Andolan*, which began in the Central Himalayan region of Garhwal in Uttarakhand in the late 1980s and which is 30 years old to save the traditional seeds of the hills. As a consequence, it preserved in situ rich variety of traditional seeds, ensuring food security and the well-being of both the people and the land (Kotamraju 2009). Women, in their primary role in seed conservation, struggled collectively to conserve the local seed. These movements solicit the crucial role played by women in hills as custodians and preservers of natural resources.

Women have unique knowledge of local species as well as ecosystems which they apply as a skill to secure sustainable livelihoods, albeit a yawning gap prevails between gender and biodiversity (Badola and Hussain 2003). The immense contributions of women remain veiled. On the contrary, it's women who bear the weight of the environmental degradation (Fonjong 2008). Appropriate efforts for enhancing their awareness on the values, management and sustainability of natural resources can offer further avenues to them for alternative sources of livelihood. Even the 20th principle of the Rio Declaration clearly recognizes the vital role of women in environmental management and development (Drexhage and Murphy 2010), thus, essentially considering their full participation for achieving sustainable development and environmental protections (Alvarez and Lopez 2013).

2.2 Gender and Livestock

Livestock is one of the key resources and a necessary livelihood activity for rural farm families which directly supports the livelihoods of over 600 million poor smallholder farmers in the developing world (Thornton et al. 2006). Livestock has potential for improving food and nutritional security besides catalysing the agricultural growth, lessening rural poverty and mitigating farm households' vulnerability to production shocks (Alary et al. 2011; Birthal and Negi 2012). Livestock as a resource provides human society in multiple ways including food, income, employment, insurance against drought or crop failure, emergency cash requirement, clothing, fuel for cooking and many others. Livestock helps in poverty elevation in three forms, viz. securing the resources of the poor at the time of need, improving smallholder farm household productivity and enhancing participation of smallholder and pastoral into market (Heffernan and Misturelli 2000; ILRI 2007).

Development of small-scale livestock-based enterprises must be a key approach for ensured food security and alleviating poverty in rural context (FAO 2010b). Livestock hold a special importance for small and marginal farmers as well as vulnerable section of rural societies, including women. The distribution of livestock husbandry-related tasks and ownership between men and women varies between regions and is strongly associated with social, cultural and economic factors. Gendered roles in livestock husbandry have been well documented (Feldestein

1990; Polomack 1989; Beshara 1987; Sah et al. 2006; Conelly et al. 1987; Nagy et al. 1989).

The work pertaining to household and the assets of the households which need regular care is usually "women's work", and livestock rearing is also one of the similar responsibilities shouldered by women in rural settings, and most of the activities in livestock rearing are performed by them like feeding and milking larger animals and raising poultry and small animals such as sheep, goats, rabbits and guinea pigs (FAO 2009). In rural livestock-based economies, women share about 67% of livestock keepers, and when they tend animals – small or large – they make its products for family diet creating a positive impact on overall household well-being (IFAD 1999; FAO 2012).

Patel (1998) gave due credit largely to the illiterate rural women dairy farmers for securing India's position as largest milk-producing country across the globe and increasing significantly the per capita availability of milk in the country. In northern hills of India, where livestock is a supplementary livelihood activity, women take care of the supply of the milk in the dairy cooperatives or nearby local dairies and also control the money earned in lieu of the sale of livestock products. In plains, where livestock rearing is primary livelihood, men either perform these activities with women or perform it alone with the help of labours. In such households, the selling of milk is controlled by men only. A study done in Karnataka disclosed about 87% of women's involvement in feeding the animals, 85% in watering of animals and 83% in grazing of animals (Rathod et al. 2011). Kathiriya et al. (2013) reported from Gujarat that 80.83% women involved in fodder collection, 75% in chaffing of fodder, 86.66% in feeding of animals, 77.50% in storage of feed/fodder and 85% in watering of animals. In Northern plain zone of Uttar Pradesh, majority of women (78%) were found responsible for livestock care and management in their households followed by performing jointly (18%) with men. In a few households (14%) only, men took the responsibility for livestock rearing. But the decision-making pertaining to livestock management was mainly taken by head of the family or husbands (Joshi et al. 2017; Joshi et al. 2016). The sale of milk in the local market or village usually remains a men dominant task and is often supported by children of the family (Okali 2012; Thornton 2001; FAO 2011). Despite the greater role and contribution of women in dairying and livestock, men mostly eclipse women in ownership of more valuable stock, making the decisions and the control of livestock production in Zimbabwe (Mupawaenda et al. 2009).

Compared to large livestock production system, women enjoy more autonomy especially with goats, poultry, quail and duck. Family poultry is one such enterprise which, besides contributing for poverty alleviation and food security, promotes gender equality in developing countries (Guéye Guéye 2004). In case of small animals, women usually have more control over their management as they are reared in the backyard of the houses and, in a way, result in more freedom among women for their sale and purchase. Men are better trained in husbandry and health management like vaccination, treatment against internal parasites, etc. (FAO/IAEA 2002). Therefore, in the countries where land ownership is often biased towards men, livestock could be the best pathways for reducing gender disparity (Jumrani and Birthal

2015). This is mainly because of the fact that livestock are such assets where no property rights apply, and they can be owned and used by women to consolidate their bargaining power in intra-household resource allocation decisions.

2.3 Gender Participation in Value Chains

The value chain comprises the full range of activities that any firm or individual perform to roll out a product from its conception to end use and beyond. More often, value chains are embedded in social context (UN Women 2011) implying thereof that markets and gender dynamics within households are linked. Agricultural production systems are usually structured by gender-based roles and responsibilities. Consequently, intervening the existing value chains affects the gender relations both – intra-household or inter-household – in one way or another. It is observed that the value chain nodes at which women are involved are often less visible or are overlooked in value chain analysis as well as value chain-based interventions, even though they are essential for enhancing efficiency and competitiveness of the value chains. Those less visible nodes include working as farm family labour and temporary work. Chen et al. (2013) have appropriately observed that the rice value chains in the Mekong Delta involved mostly (80%) middle-aged men as traders or collectors. They attributed this division of labour largely to the social and cultural norms, minimizing thereof the interaction of women with men. Even though the women farmers are eager, they often fail to derive advantage of innovations and markets (Patel et al. 2012). Any interventions made along the value chains if overlooking the underlying gender issues enhance the probability of widening the gender disparities. These disparities may be linked to workloads, earnings and economic and social injustice.

Case Study 1: Women in Millet-Based Value Chain in Eastern State Odisha

In Odisha, the eastern state of India, women were working as farmers, petty traders and labourers in processing units, whereas the traders, middlemen, owners of mills and retailers/wholesalers were usually men. Even in the works in processing units, women were kept engaged in cleaning grains, feeding the mills, operating and collecting flour, whereas men were carrying loads, weighing, account keeping and maintaining machine. Women were trading small volume of millet up to 25 kg, while men were taking charge of larger volumes. Women complained for no basic facilities and shed in markets and poor roads and transportation facilities leading to higher travel expenses in remote areas as well as exploitation by male traders by pressurizing the women to sell at low prices. In processing centres, women worked as labourers in a potentially hazardous environment full of noise and dust with no protective gears. This had potential risk for occupational health hazards among the women labourers (Jeeva et al. 2019).

3 Gender Issues in Agriculture

3.1 Women: The Invisible Farmers

The work done by women is usually not accounted for due to non-availability of standard methods to capture the demarcation between their reproductive and productive roles in an informal sector. In many societies women's work at home is valued, and women working outside home are usually considered of low esteem due to the prevailing socio-cultural beliefs (Jeemol and Jacob 1999). Characterizing women's role in agriculture as economically inactive or as merely supportive one as farmers' wives (Samanta 1994) is grossly inaccurate. Many of the developmental inequalities arise from gender bias which leads to unequal access to resources and services which eventually pushes this half of the population towards poverty being disadvantaged section. There have been quantitative evidence of how the enhanced rural to urban migration by men has led to increased number of women delivering multiple roles as cultivators, entrepreneurs and labourers (Economic Survey 2017–18). The census of India, on the other hand, reflects a declining trend of share of total women workers in agriculture by 6.8% as against by 5.9% from 2001 to 2011.

3.2 Time Poverty

Agriculture is a labour-intensive activity. At the same time, the high-intensity agricultural work may have deteriorating effect on health through fatigue, hazardous exposure, impairment to the immune system and exposure to many ailments (Chiong-Javier 2009; Habib et al. 2014). There has been a direct correlation between physical effort and energy expenditure with agricultural work which is a determining pathway to women's own nutrition and health status. The time use pattern in agriculture, livestock and reproductive roles provides evidences of workloads and energy expenditure of women farmers. In a study in Uttar Pradesh, India, it was analysed that during morning (from 5 AM to 8 AM) farm women had maximum workload followed by during 8 to 11 AM. However, during 11 AM to 3 PM, they have least workload. Thus from 11 to 3 PM may be the most appropriate time for scheduling technological interventions for women farmers. But this again varies with type and amount of support available to women in their household responsibilities (Sah et al. 2014). Synthesis of cases from four sub-Saharan African countries established that the average daily hours in agricultural works for women is almost 467 minutes a day as compared to about 371 minutes a day for men. Likewise, Tanzanian girls at every age have heavier work burdens compared to boys (Ritchie et al. 2004). Women spend considerable time on fuel and fodder collection, fetching water and picking fruits, raw materials, etc. from forests. This way they spend approx. 15.00 hours on these works as against men who spent only 2.17 hours on such activities. Collection of fuel wood emerged as one of the most engaging

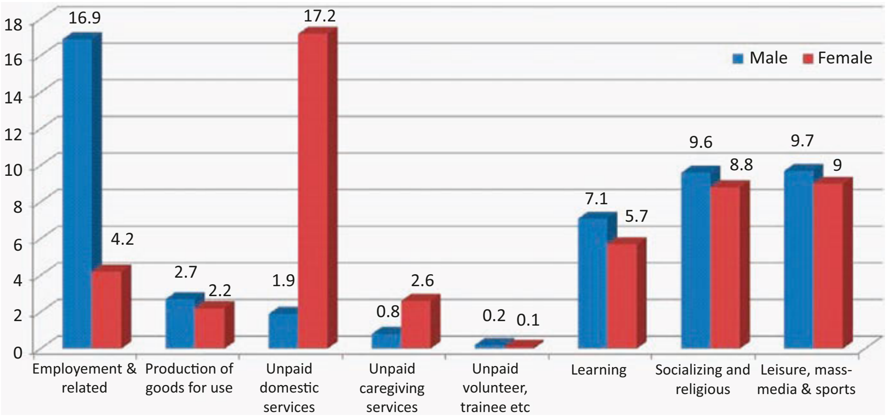

Fig. 5.2 Percent share of total time in different activities in a day/person (all India)

activities for women (Hirway 2018). The Time Use Survey (TUS) 2019 reflected that in India on an average women dispose about 20% of their daily time as unpaid domestic service providers as against 2.7% by their male counterparts. On the contrary, men spend about 17% of their daily time while women spent about 4.2% in employment-related activities. Women were also reported spending less time on learning, socializing, communicating and religious activities and leisure mass media and sports-related activities than their male counterparts (Fig. 5.2). Time poverty basically deprives women's human rights as it limits women's agency by depriving them for making choices. The burden of responsibilities prevents women from taking up income-generating activities, trainings, education and opportunities of raising their skill and even rejoicing a "me time".

3.3 Few Formal Work Opportunities and Low Wages/Income

Women are usually expected to work in unorganized sectors with flexible work schedules so that they can give equal contribution in household chores and caregiving tasks. Men are paid twice the salary of women because they do more physically intensive work that is considered unsuitable for women (ILO 2016). The glass ceiling effect is still present in many vocations including informal sectors like agriculture, where the women dominant activities, which are equally time taking and require efforts, are perceived as less valued activities and hence are less paid. Globally the gender wage gap is estimated to be 23% implying thereof that women earn 77% of what men actually earn (UN women 2018). These figures may understate the actual gender pay gaps in developing countries where informal self-employment is prevalent. Women also tend to face the motherhood wage penalty globally that increases with the number of children (Grimshaw and Rubery 2015). Globally 55.23% of women engaged in agriculture were estimated to be paid low wages (Kim 2000). Among the low-wage earners across the globe, 17% lived in poverty and 31% of them lived below poverty level (Kim 2000).

3.4 Limited Accessibility to Extension Services and Trainings

Another important factor that limits rural women for improving yield, profit and efficiency in agriculture includes the way the designing, managing and staffing of agricultural services are done (Saito and Weidemann 1990; Gittinger et al. 1990). The male bias in functioning of agricultural extension centres as well as structure is obvious. The residential training units for imparting technical skills fail to provide the needed facilities for women. Time poverty limits women from leaving home for attending this capacity-building programme. The programme targeted for women mainly focuses on topic related to their reproductive and household roles and fails to cater to their information or skill needs in productive roles. Long back in Berger et al. 1984, Berger et al. had noticed that the existing agricultural extension services were not delivering as expected for small farmers in general and much less for women farmers, and they felt some very fundamental changes required both in the type of technology being designed and in the structure of the service delivery system itself.

Women farmers were thus marginalized by male extension workers (Doorenbos et al. Doorenbos et al. 1988; Swaminathan 1985). In India, the majority of army of grassroots functionaries operating in agricultural extension system are men at the grassroots level; only about 10% of them are female (Meena and Intodia 1999). More representation of men as extension workers is also one of the reasons why women could not make a connect with the other gender and their women-specific problems often remain undocumented. Staffing the women extension agents alone will not be sufficient to reach women farmers; extension programmes must address the needs of small-scale producers because women farmers were rarely the large-scale producers often approached by agricultural extension programmes (Manfre et al. 2013). Hence, designing the specialized and need-based training programmes, approaching women in groups and reserving one-third position of extension staff for women shall ensure better access of agriculture extension services to women farmers in India.

3.5 Women Suffer Restricted Mobility

Women in many cultures suffer restricted mobility due to the socially assigned reproductive roles and caregiving tasks. This limits their exposure to the dynamics of the markets and improved agricultural technology that directly impact their livelihood. The mobility of women in marketplaces and negotiations with the market players is not received well in certain societies. Lodin et al. (2019) from sub-Saharan

African regions reported that women tend to be more constrained than men in their freedom to venture outside their homes and beyond. This in turn influences their access to agricultural inputs, trainings, farmers 'groups, and exchanges of information to learn about new technologies and practices and participation in value-adding and commercial activities.

3.6 Identity Crisis as a Farmer of Farmer's Wives

The law does not discriminate men and women as such and provides equal rights to women to ownership, inheritance and other resources, but it is deeply rooted in the socio-cultural context that women are secondary to men. Lack of ownership deprives rural women of their incentives and capacity to invest in agricultural production, impacting negatively on their earnings and limiting their participation or influence in family activities or decisions in India (Roy and Tisdell 2002). Gender inequalities in land rights are widely prevalent globally. Due to a range of legal and cultural constraints in land inheritance, ownership and use, less than 20% of landholders are women (FAO 2010). Women represent fewer than 5% of all agricultural landholders in North Africa and West Asia, while across sub-Saharan Africa, women average 15% of agricultural landholders. In Western and Central Africa, Near East and North Africa, the women land ownership is less than 10%. In contrast, in Latvia and Lithuania, women hold more than 45% of land titles. Land ownership title of women is linked to their participation in household decisions regarding the use of agricultural land and purchase of productive assets (Santos et al. (2014)). Similar empirical evidences have also been reported from across the globe (Roy 2008; Mishra and Sam 2016; Wiig 2013; Twyman et al. 2015). A region-wise disaggregation of the data of India shows persistently low female ownership of farmland in all the regions ranging from 28% in the hills to only around 8% each in the east and west (Agarwal et al. 2020).

3.7 Limited Cooperative Membership

Though the concept of cooperatives prevails across the globe, its access however varies, and disproportionately low participation of women is widely witnessed. For example, in Ethiopia women have about 20% of cooperative membership, even though they are sharing approximately half of the farmers in the country. In 2012, census of Paraguayan cooperatives revealed only one cooperative was led by a woman out of the total 45 agricultural cooperatives surveyed (Clugston 2014). No other country in the world has a cooperative movement as intricately diverse as India, but the participation of women in cooperatives is not much encouraging. More objectively, a study disclosed that 19 out of 26 countries in Asia Pacific revealed that while the ratio of women chairpersons increased from 7% in 2005 to

10% in 2016, the number of women leaders at the top remained abysmally low (Azad 2018). Lack of women's representation at the top could be attributed to patriarchal values and lack of education and skills that restricted access to leadership positions.

3.8 Inequitable Decision-Making

Many women dominant tasks in agriculture and allied activities are decided by the male counterparts. Women usually do not make decisions which are pertaining to their family and even pertaining to them as well. When men are away, they usually take decisions regarding the daily activities and familial issues, but rarely take decisions related to the productive resources which is an important indicator of empowerment (Malhotra et al. 2002; Nosheen et al. 2010). Having a say in intra-household decision-making is considered an integrally meaningful dimension of empowerment as it affects directly resource allocation within the households (Peterman et al. 2015). Evidence from studies on women's empowerment suggests that when women have a larger role in decision-making, household well-being improves (Sell and Minot 2018; Meier zu Selhausen 2016).

3.9 Women-Headed Households Are Resource-Poor Households

National Sample Survey Organization (NSSO) report states that women-headed households are poorer than male-headed households in terms of less access to concrete houses, less income sources and poor purchasing power. As females are less equipped with skills of income generation, they are not able to take up a better job in labour market. Because of restricted mobility due to cultural taboos, they cannot search jobs at various workplaces, and several times they are less preferred at workplace in comparison to their male counterparts. In the labour market, women will be paid lower wages even when government has made clause for equal wages for equal work to both genders. From the primary survey in the selected districts, a wide wage differential was reported by women labour where the rates for men were as high as ₹ 300–350 per day while the highest being paid to women was ₹ 200–250 per day. Many studies support this discrepancy in agricultural wages (Waris et al. 2016). Rural households value childbearing over women's wage income. In this context, women's work becomes secondary and undervalued considered supplementary as opposed to primary income (Akter et al. 2017). In many cases, the households are being run by females as heads, but in records, they are mentioned as women-headed households as men have the ascribed role of bread earner. Bavinck and Gupta (2014) also argued that in developing countries, owing to strong patriarchal values, households are more likely to be classified as male-headed when in reality they are female-headed.

3.10 Heavy Workloads and Ignored Occupational Health

Majority of agricultural activities, which are full of drudgery, have not been supported by the mechanical advantages of tools and appliances. While doing agricultural operations, the farmers adopt many unnatural postures like bending and stretching of different body parts that lead to increase in cardiovascular stresses. Many of the health problems of these women which include muscle, joint and bone-related problems are occurring because of their strenuous work activities. Adopting inappropriate tools could lead to posture, spine and musculoskeletal problems, or worse, to accidents and physical injuries (ILO 2000). In the field survey, when women were asked about the extent of pain experienced during weeding activity, they said that it is their routine work and they have to do it, so why should they complain about pain? (Joshi and Chandra 2019). Introducing women-appropriate technology has illustrated the additional benefits of shortened work hours or reduced labour input that free woman from farm work to attend to other domestic responsibilities (OWID 1997).

These gender-based constraints and issues are more or less common in all the sectors pertaining to agriculture broadly – be it cereal production system, pulse-based production system or commodity value chains. As the gamut of issues are widespread and broad, fixing these issues for mainstreaming gender concerns requires a multi-sectoral approach with engagement of policymakers.

4 Strategies for Mainstreaming Gender Concerns in Agriculture and Allied Sectors

Mainstreaming gender is complementary and essential for attaining the gender parity in its inclusive sense. Empowerment in literal sense means the act of giving power and authority to someone. Women empowerment contemplates of granting women the actual decision-making as well as influencing the decisions besides enjoying the economic, social and civil freedom. Enhanced levels of income, skills and self-confidence are the enablers of women empowerment. A broad-basing approach, from policy level to implementation stages, is inevitable to bring farm women into the mainstream and empowering them with direct access to knowledge of technical and improved agricultural practices (Munshi 2017). The process of empowerment of women farmers demands educational and technological interventions, including feasibility trials and knowledge sharing (Patel 2016). Some of the possible strategies may include the involvement of women in the higher level of value chain and strengthening their role in the different nodes of these chains which may require a mix of approaches varying from culture to culture and region to region. Similarly, capacity-building programmes form the basis of human capital besides equipping the right skills among women to initiate new ventures. Studies in Bangladesh showed how training intervention on home gardening increased participating women's (i) per capita production, (ii) production and consumption diversity, (iii) frequency of harvesting and (iv) ensured supply of micronutrients and vitamins (Baliki et al. 2019; Schreinemachers et al. 2015). Engendering needs to be done in all aspects of farm and homestead-level mechanization. It has to begin with gender analysis of activities, gendered effects on workers' body and the design of gender-responsive mechanization technologies and training programmes (FAO 2004; Sims and Kienzle 2006, Kormawa et al. 2018). Several instances have confirmed the successful integration of mechanization among women farmers, like use of fodder choppers (Kiyimba 2011, Fischer et al. 2018), reaper-harvesters (Theis et al. 2019), maize shellers (Joshi et al. 2018) and groundnut shellers (Orr et al. 2016).

Women's collectives and FPOs provide a space for women to come together in groups with unified aim of production, adding value and marketing their produce jointly and even the household access to agricultural credit, especially in ensuring the access to micro-credit programme (Evans et al. 1999). Similarly, women cooperatives shall augment income-generating opportunities, and the delivery of benefits shall not be directly related to production (social services), but shall have better impacts on farmers' livelihoods (Birchall 2003). One of the cooperative models in India is Self-Employed Women's Association (SEWA) which has over 1.24 million women members, 54% of whom are agricultural workers, to empower marginalized rural women and informal sector workers through grassroots campaigns and social mobilization and ensure their access to services (FAO 2016).

Because the majority of the government's initiatives benefit household heads and those who legally own land; girls, women, and widows are left out because they do not automatically inherit their deceased husband's property — it may go to his relatives or their sons (WEF 2017). Poverty, resource-poor status and injustice towards women will be eradicated only when equality and rights for women are secured (Action Aid 2012). Thus, the gender transformative approaches in agriculture shall minimize the gender gaps leading to higher productivity and economic gains truly cherished by women in farm households (Diiro et al. Diiro et al. 2016).

Case Study: FAO Project on Enabling Women to Benefit Equally from Agri-food Value Chains in Ethiopia (FAO 2016)

One of the good examples of strengthening women's role in value chain is FAO project in Ethiopia. The project was aimed to develop inclusive business models throughout the cassava value chain. It leveraged the use of techniques tailored to the specific needs of female farmers, which reduces their labour so that they can increase productivity and incomes. Female producers and processors received multiple trainings on different issues, including improved production practices to business and marketing skills. A better understanding of the opportunities in the market and their unique advantages in the value chain enables female farmers to be informed on how to be competitive in the market and to ultimately increase their profit from the sale of cassava

(continued)

products. The institutions were also made gender sensitive by training extension officers on how to identify gender-based constraints and analyse and address the impacts related to gender. Institutional capacity development, even through formal legal representation of women's cooperatives, ensures that while reinforcing the individual capacities of female farmers, the enabling environment is also supportive and inclusive of women in the value chain.

5 Conclusion

Ensuring gender equality in agriculture involves ensuring the empowerment, agency and inclusion of women in the agriculture sector. Mainstreaming gender in agriculture requires change in individual capacities in form of human capital, the expectations embedded within the social system and change in the rules and practices of the institutions involved. Time has come to design and implement gender transformative approaches. **A** gender-transformative approach means that promoting gender equality – the shared control of resources and decision-making – and women's empowerment is central to an intervention. Such interventions are to be planned which bring an intrinsic change in the women as well as change in the attitude of the persons in their micro- and meso-system. There is a need to create an enabling environment through behaviour change communication at community, institutional and policy level so that the effect of the interventions remains sustainable. The gender-responsive approaches can bring change in the existing gender positions, vulnerabilities and challenges, but gender transformative approaches will ensure sustainability of the gender equitable changes brought through the interventions. For this, men and boys – the opposite gender – are required to be sensitized well as a change agent as well as a change promoter.

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Chapter 6
Characterization and Appraisal of Crop-Based Farming System for Sustainable Development of Agriculture

Vinay Prasad Mandal, Aishwarya, and Pavan Kumar

Abstract The socio-economic implications of the novel agricultural practices have been studied by many of the social scientists. Such studies contrast from micro to meso and national levels. The degree of overall transformation in the combinations of crops in space and time has, however, not been studied at national level. Apart from the physical environment, changes in the socio-economic conditions and land tenure have brought change in cropping patterns and thus made the structure of the Indian agriculture non-rigid. The present effort is a modest challenge to make appraisal of crop-based farming system for sustainable agricultural development. The study was carried out for characterization of land resources of overriding farming systems of Katihar district in Bihar. The evaluation of land resources for Land Utilization Index (LUI) was done by Sentinel-2 along with farmers' surveyed data in GIS domain. Spatial distribution of NPK (nitrogen, potassium, and phosphorus), organic carbon, electrical conductivity, and pH were analyzed for assessing soil health and physiognomies. These indices were also used to devise agricultural land utilization index for suggesting cropping patterns. Agricultural land resources and their characterizations were categorized on the basis of seasonal cropping practices in the study area as single, double, and triple cropping pattern along with productivity. The study revealed nutrient availability, number of irrigation intensity, slope, and seasonal variation of

The original version of this chapter was revised. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-93258-9_17

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_6

crop vegetation (Kharif and Rabi) index and validated productivity available in the study area based on the combination of different agricultural practices.

Keywords Land resource · Land utilization index · Soil micronutrients · Characterization

1 Introduction

The natural resource base of India is so rich that it has often been called as a "rich country of poor people". In fact the Indian soil is rich, yet its population is suffering from malnutrition and undernutrition. Agriculture, the backbone of the Indian economy, not only feeds the teeming millions of people but also provides raw material to the agro-industries and thus has a dominant role in its export performance (Shulka et al. 2009; Abrol 1999; Allan et al. 1997;Binswanger and McIntire 1987; Bisht et al. 2014; Brookfield 1993). The cause of Indian poverty, economic-backwardness, and underdevelopment is generally attributed to the social structure, law of succession, small and fragmented holding, superstitions, orthodoxy, caste restriction, and irrational distribution of the means production. In the past, the Indian export of agricultural products, for the most part, paid for imports of manufactured goods which resulted in stunted growth of the agricultural and industrial sectors (Manda et al. (2014), Wakene & Heluf (2003); Brüntrup 1997; Challinor and Wheeler 2008; Dodds et al. 2009).

Indian agriculture was organized, traditionally, not as an industry but as an activity for marginal subsistence of the bulk of the population. Consequently the farmers' motivation by and large was not to create massive agricultural surpluses for supporting other modes of economic activity but merely to produce enough to satisfy the minimum requirement of the enormous population dependent on agriculture (Dunjo et al. 2003; Getachew and Heluf 2007; Groot et al. 2012; Haroon and Iffat 2016). The traditional agriculture which was based on empirical experience of the cultivator was improved to the point of being perfected. It has adapted itself to the resources, soil fertility, and requirements of the people (Hodgson et al. 2010; Howarth et al. 2002; Kates et al. 1993). In the last three decades, the Indian planners and social scientist have been concerning to transform the subsistence farming so that higher agricultural returns could be obtained. There is no doubt that the agricultural occupation is undergoing change, especially through the application of new technology (Kingston and LaGrade 1972; Kumar et al. 2013, 2016).

The analysis of cropping pattern, crop concentration and agricultural operations is imperative for suggesting crop combinations in a given region (Mohammed et al. 2005; Netting 1993; Pandey et al. 2015, 2016). The crop combination on the one hand gives an idea about agricultural typology, agricultural economics, and agricultural income of a region, and on the other, it provides an insight to the cropping practices and rotation of crops which are quite pertinent for the maintenance of soil fertility and its health (Panigrahy and Sharma 1997; Panigrahy et al. 2005). Indian farmers on the basis of their long experience as cultivators have adopted certain crop to be sown in *Kharif* (summer) and *Rabi* (winter) seasons. The area devoted to each crop is determined by the physical and socio-economic conditions of the individual farmers. There are very few crops which are cultivated against the physical milieu as by doing so the farmers are exposed o great risks of climatic hazards (Pingali 2007; Lal 2008). The term land resource basically refers to agriculture resource and its utilization pattern. Land use and its management influence most of the agriculturally appropriate soil morphological, physical, chemical, and biological physiognomies (Rounsevell et al. 2005; Bobade et al. 2010; Pratibha 2010).

2 Material and Methodology

2.1 Study Area

Katihar, an agriculturally prosperous district of the northeastern part of Bihar state in India, lies between 25°13′ and 25°53′ N latitudes and 87°12′ to 87°04′ E longitudes. It occupies an area of 3057 Km². The rivers named the Ganga, Kosi, Mahananda, and Righa are its lifelines (Fig. 6.1). The Kosi river and the Mahananda river flow with their numerous tributaries corresponding to Morabrandi Nadi, Saura Nadi, Pamar, Dhar, Kamla, Nagar drain, and Fariyani Nadi. Katihar is located in the

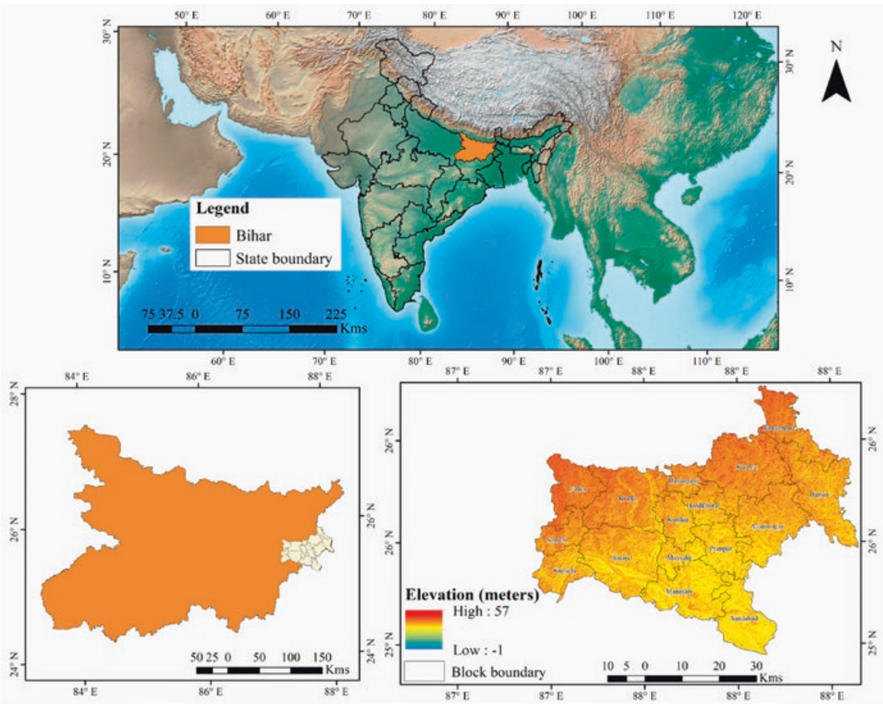

Fig. 6.1 Location map of study area

plains of the northeastern part of Bihar state and bounded by Purnea in the east, Maldah (West Bangal) in the west, Kishanganj in the north, and Sahebgunj (Jharkhand) in the south. The physiographic and climate diversity of India is matched by the variety of composition, structure, and texture of its soils. The soil of Katihar district varies from the younger alluvial (Khadar) to the lateritic soil developed. The soil in which the cultivators grow their crops is itself a product of the interaction of climate upon the materials of the earth surface.

2.2 Satellite Data and Pre-processing Analysis

Senstial-2 October 2016 for *Kharif* and Senstial-2 January 2017 for *Rabi Season* (Spatial resolution of 10 m) with high-resolution data were used to formulate lithology, physiographic, and land descriptive analysis. Image pre-processing included the removal of distortion, both geometric and radiometric, and mathematical transformation. Pre-processing was carried out to make the data more easily interpretable for analysis. Geometric correction was carried out by employing transformation, T, which maps a distorted image, $f(x, y)$, into a corrected image, $f(x', y')$, namely, $f(x', y')$ equal to $f(x, y)T$ for all x, y, x' and y'. Conceptually this correction encompassed system geometries, empirical functions, scale changes, and variable map projection. Sometimes a projective transformation is approximated on a sub-image basis by linear transformation. In this case, the transformation, T, is expressed as (Tripathi et al. 2017):

$$T = \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \text{forthesubimage,} \tag{6.1}$$

and the corrected grid position, x', y', is determined by

$$x' = \frac{a_{21} + a_{22}x + a_{23}y}{a_{11} + a_{12}x + a_{13}y} \tag{6.2}$$

$$y' = \frac{a_{31} + a_{32}x + a_{33}y}{a_{11} + a_{12}x + a_{13}y} \tag{6.3}$$

2.3 Field-Based Investigations

In the year 2016–2017, ground truth data was collected using the handheld GPS along with block-wise parts of Katihar district. Ground truth information from each farmer's field data and practices of decades are indicators for farming systems. All enterprises with households information was collected farmer-wise in the district. Other side under the ancillary data like administrative boundary and other basic or statistics data was collected for reference purposes. The stratified random sampling has been performed for 16 blocks and 48 panchayat of the study area, and 70% of the area was composed of rice-maize systems. Field cultivation of crop rotation and farming practices for farmer's selection was a measure more than 10 years consecutively. The Farmers plot was cross-examined for their current crop supervision observes, nutrient use, Rice and Wheat production levels during 2016–2017. About 160 surface soil samples (0–30 cm) were collected physiographically by using GPS from 16 blocks of Katihar district, viz., Kursella, Falka, Sameli, Barari, Korha, Katihar, Hasanganj, Dandkhora, Mansahi, Manihari, Amdabad, Pranpur, Azamnagar, Kadwa, Barsoi, and Balrampur during 2015–2016. The available N, P, K, Zn, Cu, Mn, Fe, and B along with pH, EC, and organic carbon were analyzed in the laboratory as per the standard procedures.

2.4 Statistical Investigations

Single band may not be sufficient to extract desired information. The main research objective is to increase information or highlight cultivated land by cultivated land utilization index (CLUI). The information was added to form a single-band image. The linear combination, one of the digital multiple band transformations, generates output image by combining two or more bands following a linear operation transformation (Eq. 6.1) to have desired effect.

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 \ldots\ldots\ldots + a_nx_n \tag{6.4}$$

where $x_0 + x_1 \ldots\ldots x_n$ are the gray values of a pixel in different bands; Y is the output gray value, and a_0, a_1, $a_2 \ldots.$ a_n are the coefficient.

Based on the linear combination, we generated cultivated land utilization index (CLUI).

$$CLUI = a_0 + \sum_{i=1}^{n} \left(\frac{a_i * d_i}{A * 365} \right) \tag{6.5}$$

where

n= Total number of crops
ai= Total area occupied by the ith crop
di = No of days that the ith crop occupied
A = Total cultivated land area accessible for 365 days

3 Result and Discussion

3.1 Major Cropping Systems

A survey was organized through major cropping systems in Katihar district as conjoint cropping systems, while at panchayat level, analysis can be done by some different cropping systems at some blocks. Another most important as farming systems characterization which is inland fisheries here is compressional to high area in reprisal to another block. Both Balrampur and Barsoi blocks are under low land area. Due to heavy rainfall, most of the lands are water-logged area, in Barsoi blocks. It is also observed that such type of conditions falls in some part of Mansahi, Pranpur, Azamnagar, and Amdabad blocks. Major cash crops found are vegetables and second one is Jute due to low urbanization and availability of market. In this consequence Hasangunj, Korha, Mansahi, and Katihar blocks produce vegetables. Banana is as cash crop (horticulture) in Katihar district, but it is dominant only Barari, Kursela, Korha and Manihari blocks Fig. 6.2. Some farmers practice banana with turmeric or vegetables. Under the high productivity blocks are Falka, Korha, Manihari, Kursela, Sameli and some parts of Barari and Mansahi shown in Table 6.1.

3.2 Variability and Spatial Distribution of Soil Nutrients

Maize was a dominant *Rabi* crop of the Indo-Gangetic Plain extending as far east as the middle of the North Bihar Plains. It was the most dominant *Rabi* crop of north-western Bihar in the pre-tube-well irrigation period, i.e., before Independence. The availability of dependable water in the form of tube-well irrigation has largely

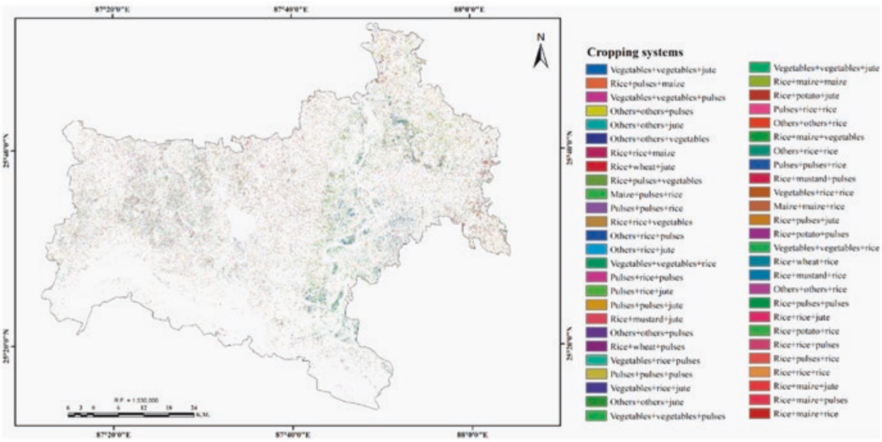

Fig. 6.2 Identified crop-based cropping systems in Katihar district (2016–2017)

Table 6.1 Cropping intensity and systems yields with systems land holding

Cropping systems	Yield (t/ha)	Average land holding (/ha)	Farmers (%)	Average no. of irrigation
Rice-maize	7.2	2.6	32.0	6.6
Rice-wheat	5.4	2.1	11.9	3
Rice-mustard	6.2	2.5	7.9	3.2
Rice-rice	5.0	2.1	3.0	5
Rice-potato	6.6	2.5	3.5	5
Rice-vegetables	5.3	2.1	0.9	7.2
Rice-pulses	5.0	2.0	3.0	3
Rice-tobacco	6.5	2.3	2.4	6
Rice-alsi	5.9	2.5	1.3	4
Maize-maize	17.2	2.4	7.1	11
Maize-wheat	15.8	2.4	1.1	6
Maize-pulses	7.8	2.8	0.5	6
Maize-alsi	4.2	3.0	0.5	5
Maize-vegetable	18.1	2.5	0.1	13
Jute-maize	6.7	2.5	4.3	5.6
Jute-wheat	4.9	1.9	2.9	3
Jute-rice	3.9	1.3	0.5	6
Jute-potato	5.6	1.8	0.4	2
Jute-pulses	4.8	0.8	0.2	4
Jute-alsi	3.4	1.5	0.4	2
Vegetables-Maize	8.9	1.9	2.2	9.3
Vegetables-Wheat	7.0	1.7	0.3	6
Vegetables-Mustard	11.2	2.7	0.4	7
Vegetables	10.6	2.5	2.6	9.5

displaced maize by rice, so much that the young generation of farmers might not be aware that decade ago their principal *Rabi* crop was maize or a combination of maize and rice (Tubiello and Ewert 2002).

The Spatial discrepancy of high range available N 200 to 300 kg ha^{-1} recorded at Korha blocks and medium range available N 180 to 200 kg ha^{-1} recorded at Falka, Kursela, Sameli and Barari. Lower range of study area available N 130 to 150 kg ha^{-1} recorded at Azamnagar, Barsoi, and Balrampur at altered locations shown in Fig. 6.3. Pattern of available N increase at Pranpur, Kadwa blocks which are located eastern part of Mahannda application of 160 to 180 kg N ha^{-1} and similarly as available N increase at Mansahi, Amdabad and Manihari blocks which are located west/eastern part of Mahannda application of 180 to 190N kg ha^{-1}. The highest P was recorded at Kursela 29 kg ha^{-1} and the highest K rate was verified at Manihari 152 kg ha^{-1} (Table 6.2).

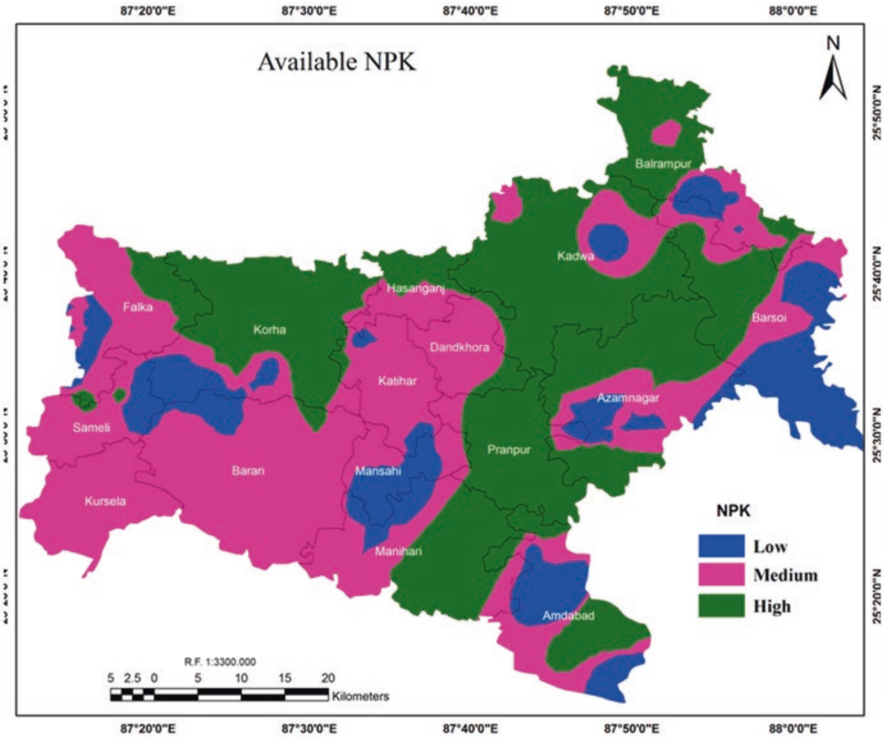

Fig. 6.3 Map of spatial variability of available nutrients

Table 6.2 Distribution of available nutrients

S L	Block	pH	EC (dS/m)	OC (%)	Available nutrients (Kg/ha)		
					N	P	K
1	Azamnagar	7.43	0.28	0.48	139.54	11.58	137.65
2	Amdabad	6.94	0.21	0.59	180.51	11.30	99.23
3	Barari	6.80	0.23	0.43	182.73	14.63	117.92
4	Balrampur	5.96	0.27	0.52	159.81	13.99	120.85
5	Barsoi	6.70	0.22	0.53	151.57	12.27	82.21
6	Dandkhoda	6.69	0.22	0.58	180.64	11.64	97.66
7	Falka	6.67	0.20	0.56	180.62	11.62	97.64
8	Hasangunj	6.81	0.24	0.37	177.19	5.52	122.71
9	Kadwa	7.53	0.28	0.18	191.29	17.25	133.18
10	Katihar	7.07	0.18	0.55	171.35	10.71	116.19
11	Koda	6.89	0.19	0.69	202.74	19.73	125.28
12	Kursela	6.50	0.17	1.28	183.74	29.54	73.02
13	Manihari	6.82	0.13	1.84	197.97	12.09	152.93
14	Mansahi	6.95	0.23	0.47	158.25	11.48	108.75
15	Pranpur	6.20	0.27	0.58	176.91	13.65	118.16
16	Sameli	6.65	0.18	0.54	180.60	11.60	97.62

3.3 Crop Yields with Irrigation Intensity

The most obvious effect of irrigation can be discerned in the differences in the extent of the area sown more than once in the district. The integrating farmer practices resulted for utilizing the marginal and sub marginal as compare to small holding size of land.

There was not much difference in the characteristics of the sites on which Korha and Falka were excavated. Accordingly, the majority of the areas represented by both Barari and Manihari studied were cultivated for maize, wheat, and other field crops. The site where Mansahi and Pranpur was located is very gently sloping (1.0–2.0% slope) with slight to moderate sheet erosion. On the other hand, the site of Barsoi and Balrampur is gently sloping (2.0–5.0% slope) affected by moderate sheet and slight rill erosion. Similarly, the soils on both sites were developed from basalt parent material, and both were very deep (>200 cm) and moderately well to well-drained. In rice-maize system, rice is irrigated by flood method, while maize or others are by boarder pumping set. Under high level of irrigation in Korha, Falka, Kursela, and Sameli region, rice-maize and rice-vegetable and banana cropping system were found better improved, and rice-rice cropping systems in Barsoi, Balrampur, Azamanagar, and some parts of Kadwa or Amdabad blocks were found extremely remunerative with high use of water. Similarly Makhana alone is more remunerative (Fig. 6.4).

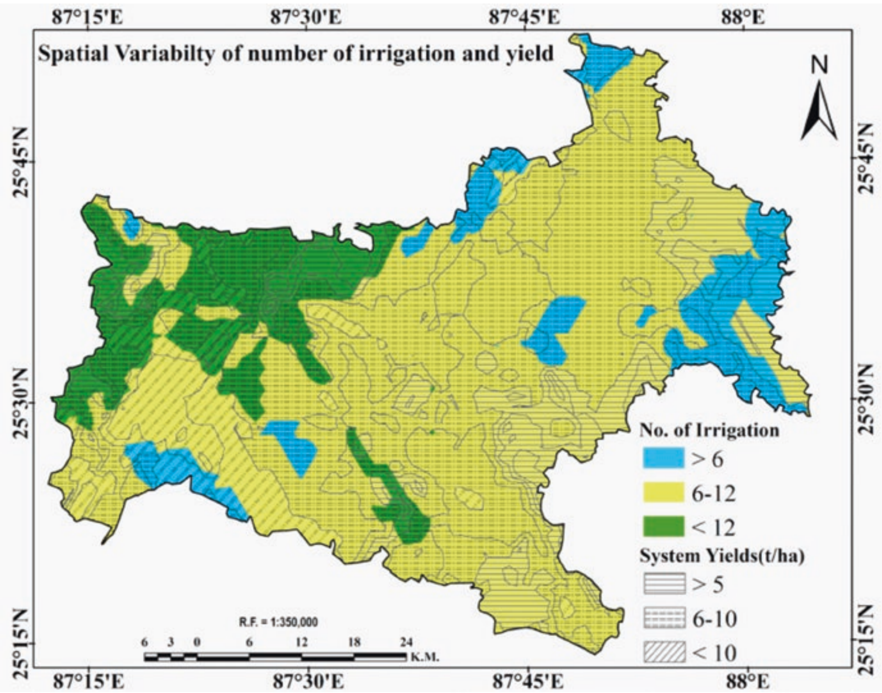

Fig. 6.4 Crop yields with irrigation intensity

3.4 Land Resource and Land Utilization Index

The 16 blocks of Katihar district and its pattern of agriculture practices fall under 24% of total area. Built-up area covers 2.14% in study area. Urbanization of population in study area is very low at local market as behind railway station (Tomar et al. 2014; Versteeg and Koudokpon 1993; Von Braun 2007). The drainage systems and channel are very complex in the study area which is occupying 7.4% area (Fig. 6.5). Agricultural scrub area is relatively low only in Dandkhora and Amadabad out of 16 blocks of Katihar district, i.e., 19.4%. Further, the percentage of water bodies extended 27.1%, and sandy area covers 13% via diayara land with single cropping pattern. All the built-up area is well connected by the transportation facilities. This is well connected by the railway lines which are directly connected to Patna, Kolkata, New Jalpaiguri, and Assam and its facilities.

3.5 Complex Relation of LUI and Systems Production

The seasonally variable distribution of moisture in the form of rainfall thus emerges as the most important parameter in the agro-climatology of India. Within the wide temperature limits of what way are termed as endless growing season, agriculture

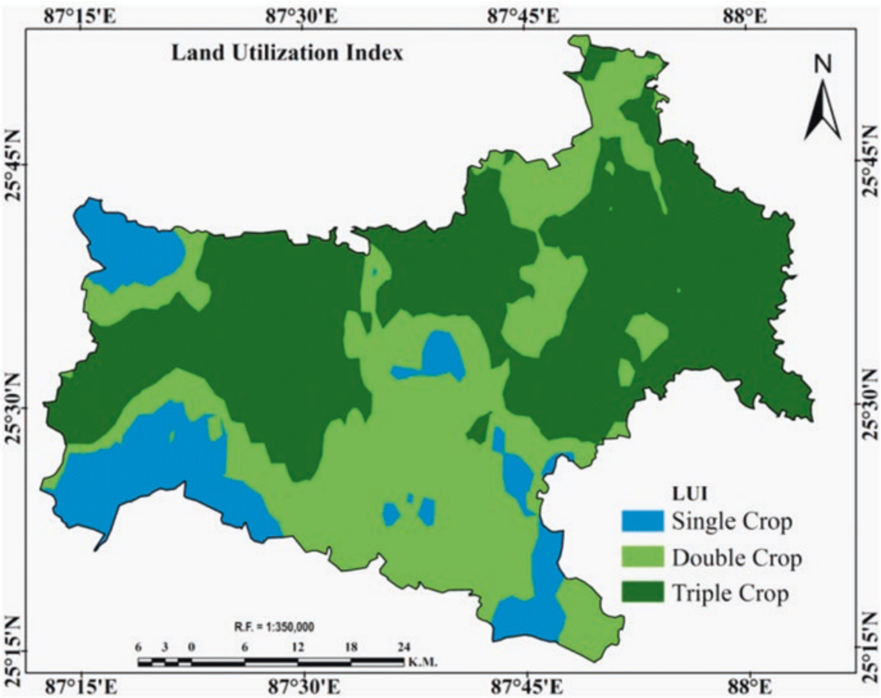

Fig. 6.5 Map of cultivated land utilization index

Table 6.3 Land utilization index through irrigation intensity and crop yields

Categories of LUI	Farmers (%)	Yield (t/ha)	Average land holding (/ha)	Average no of Irrigation
Triple cropping	36.5	8.5	2.3	6.9
Double cropping	43.0	7.9	2.5	5.4
Single cropping	21.0	6	2.6	6.2

over the bulk of Indian territory is directly related to moisture factor. In certain areas a water supply is being ensured by introducing surface flow irrigation (Wang and Yu 1975).

Water is one of the basic determinations of productivity as most of the other elements of package technology in agriculture. The use of fertilizer depend upon availability of assured water; in consequence the study area is more capable for availability of irrigation water to supplement for water requirements. The level of land utilization of the present agriculture potentials largely depends on a number of cropping systems and number of irrigation (Table 6.3). Land utilization also depends on the levels of interaction with the existing potentials and environment components. A fairly high cropping intensity ensured provided a judicious land utilization index.

3.6 *Crop Yield and Regression Analysis*

A large number of regression analyses can be modelled as two-dimensional linear system approach. Here x (m, n) and y (m, *n*) represent the yield (t/ha) and average number of irrigation, respectively, of a two-dimensional approach;

$$y(m,n) = \ncong \left[x(m,n) \right] \tag{6.6}$$

If any linear combination of two variables x_1 (m, n) and x_2 (m, n) produce the same combination of their respective output s$y_1(m, n)$ and y_2 (m, n), i.e., for arbitrary constant a_1 and a_2 (Kumar et al. 2016)

$$\begin{aligned} \ncong \left[a_1 x_1 (m,n) + a_2 x_2 (m,n) \right] &= a_1 \ncong \left[x_1 (m,n) \right] + a_2 \ncong \left[x_2 (m,n) \right] \\ &= a_1 y_1 (m,n)]+ a_2 y_2 (m,n)] \end{aligned} \tag{6.7}$$

Above equation shows the linear superposition between crop yield and average number of irrigation. The result is highly significant of r^2 0.72 which shows that if we increase the number of irrigation with particular crop then crop yield would be also increased (Fig. 6.6).

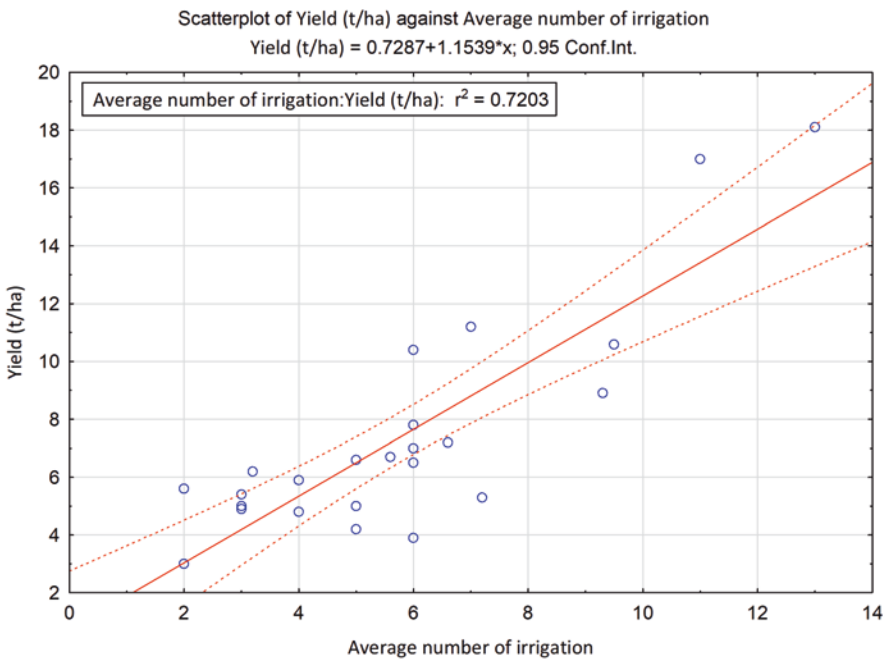

Fig. 6.6 Crop yield and regression analysis

$$\text{Yield}\left(\frac{t}{ha}\right) = 0.7286 + 1539 * x \,\text{at}\, 95\% \,\text{confidential interval} \tag{6.8}$$

4 Conclusion

Although India has made significant progress in technological development in the field of agriculture, the productivity of land and labor still remains low in terms of world standard. The technological breakthrough in terms of green revolution has helped only to maintain and not to improve the per capita availability of land holding capacity due to rapid growth of population. Unless further technological advancements are achieved, almost in an unbroken chain, even maintaining the food consumption level in future would be difficult and improving it would mean a major challenge. In the present situation when political imperatives play an important role in bilateral cooperation, a new direction can be given to agricultural research only by bringing about a change in the crop-based farming system for integrated development of agricultural pattern.

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Chapter 7
A Perspective View of Nitrogen: Soil, Plants and Water

Bharat Lal, Vinod Nayak, Abhishek Kumar, and Pavan Kumar

Abstract Nitrogen is an essential primary nutrient for production of food grains. It plays a key role in photosynthesis because it is a basic component of chlorophyll. Plant can take up only the NH_4^+ and NO_3^- forms of nitrogen from the soil solution and utilize those forms for their metabolic requirements. In natural ecosystems, organic nitrogen (rather than inorganic nitrogen) is the predominant source of crop nitrogen and comes from decomposition of organic matter in soil. In agricultural systems, crop residue, manure from crop waste and animal waste, synthetic fertilizers, nitrogen fixation and biofertilizers are sources of soil nitrogen that supply plant demands for nitrogen. Not all applied sources of nitrogen are readily available for plant uptake, because it takes time for the nitrogen to be converted into usable forms via the mineralization process. Since the green revolution, more nitrogenous fertilizers (rather than organic sources of nitrogen) have been applied to soil to optimize crop yields because they have been shown to increase yields of fertilizer-responsive crops and their varieties. Urea and ammonium sulphate are the fertilizers most widely used in India; however, applied fertilizers have low efficiency because most parts of the fertilizer fractions are lost to the surrounding environment, where they can cause serious health hazards for all living things. Major nitrogen loss processes such as denitrification (N_2 or N_2O), leaching (NO_3^-), volatilization (NH_3) and surface runoff (N) are involved, and these losses cause various environmental impacts: global warming gas emissions, nitrate pollution of groundwater, eutrophication of surface water etc. At present, the human population of India is increasing day by day, and it is a big challenge for all agriculturists to

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_7

maximize food grain production to supply the demand. Thus, nitrogen should be utilized in an integrated manner, rather than through single synthetic fertilizer application, to avoid environmental degradation.

Keywords Nitrogen · Mineralization · Denitrification · Nitrate pollution · Emission

1 Introduction

Nitrogen is an essential primary nutrient for plant growth and development. It is vital for production of good-quality crops. The world population will reach 9 billion people by 2050; thus, a 1.7-fold increase in food production will be required to fulfil the demands of the growing population (Hirel et al. 2007). That will increase the current pressures on land, water and other resources because they are constant natural resources and yet we need to produce more food from these limited resources. Intensive agriculture requires huge application of synthetic fertilizers, which are lost from agricultural fields and are detrimental to the environment (Huang et al. 2017). Since the 'green revolution' in the 1960s, increasing amounts of synthetic fertilizer have been applied. One consequence of this is a reduction in storage of carbon in soil, due to less application of manure (Hirel et al. 2007). In agricultural systems, about 50–75% of the applied nitrogen fertilizer is lost from the soil (Raun and Johnson 1999; Bertrand et al. 2011). Agriculture is responsible for two-thirds of N_2O emissions, through direct and indirect emissions. Direct emissions occur from soil fertilizer and manure application, manure management, crop residue etc., whereas indirect emissions occur from runoff and downwind nitrogen deposition on soil. The gap between nitrogen demand and supply is the reason for N_2O emissions in cropland areas (Zhang et al. 2017). Worldwide, cropland soil emits approximately 3 Tg N_2O/year. Addition of organic fertilizer not only helps to supply plant nutrients but also improves the physical qualities of the soil (such as its bulk density and water-holding capacity) and its biological quality by providing a food source for microorganisms in the soil (Yang et al. 2019; Zhang et al. 2015). The annual crop residue production in India is about 500 million tonnes, of which 34% comes from rice, 22% from wheat and the remainder from other crops (Bimbraw 2019). Mismanagement of crop residue and manure (waste from the livestock sector) also release global warming gases into the environment. The different side effects of nitrogen loss include global warming, air and water pollution, acid rain and biodiversity loss, which ultimately have negative impacts on ecosystems (Hayashi et al. 2021; Erisman et al. 2013). Nitrate leaching causes loss of soil fertility and nitrate pollution of groundwater; the latter is harmful for human health when the affected groundwater is used continuously as drinking water (Cameron et al. 2013). Ammonia volatilization also causes important losses of nitrogen at higher soil pH levels and in high-temperature (>45°C) conditions. Globally, ammonia losses range from 10% to 19% (average value 14%) of applied nitrogenous fertilizers. Different studies of urea fertilizer application have reported NH_3 losses of 30–39% from rice crops (Cai et al. 2002), 16–24% from compost (Qiu et al. 2020) and about 60% from livestock manure management (Wang et al. 2019; Hansen 2019). Between 1750 (in the pre-industrial era) and 2017, atmospheric N_2O concentrations rose from 270 parts per billion by volume (ppbv) to 330 ppbv. Between 2001 and 2015, an increase in N_2O of 0.85 ppbv/year was observed (Wells et al. 2018).

Nitrogen gases include N_2O, NO, N_2 and NO_2. When N_2O is emitted into the environment, it has >300 times more global warming potential than CO_2 does; thus, it plays a key role in climate change.

2 Nitrogen in Soil–Plant Systems

Nitrogen is a very important nutrient in soil and the most frequently deficient one for plant production. The atmosphere is a huge source of N_2, which can be fixed in soil, in seawater and in living and non-living bodies of different organisms. Table 7.1 shows the percentage distribution of nitrogen in soil–plant–animal–atmosphere systems.

Source: Havlin et al. (2005)

The nitrogen cycle and all processes involved in it are dynamic and simultaneously maintain equilibrium in the system, as depicted in Fig. 7.1.

2.1 Forms of Nitrogen in Soil

Soil consists mainly of two major forms of nitrogen: organic and inorganic nitrogen. Inorganic nitrogen includes ammonium (NH_4^+) and nitrate (NO_3^-). Organic forms of nitrogen account for more than 90% of the total nitrogen in soil but cannot be taken up by plants. Organic nitrogen is made available to plants by decomposition of certain microorganisms in soil through mineralization and nitrification processes. Plants can take up only inorganic forms of nitrogen (i.e. NH_4^+ and NO_3^-).

Table 7.1 Nitrogen sources in different systems

Nitrogen source	% contribution to total nitrogen[a]
Atmosphere	99.38
Sea	0.61
Soil	0.0038
Plants	0.00038
Soil microbes	0.00015
Land animals	0.000005
Humans	0.00000025

[a]The values do not add up to 100, because of rounding
Source: Havlin et al.(2005)

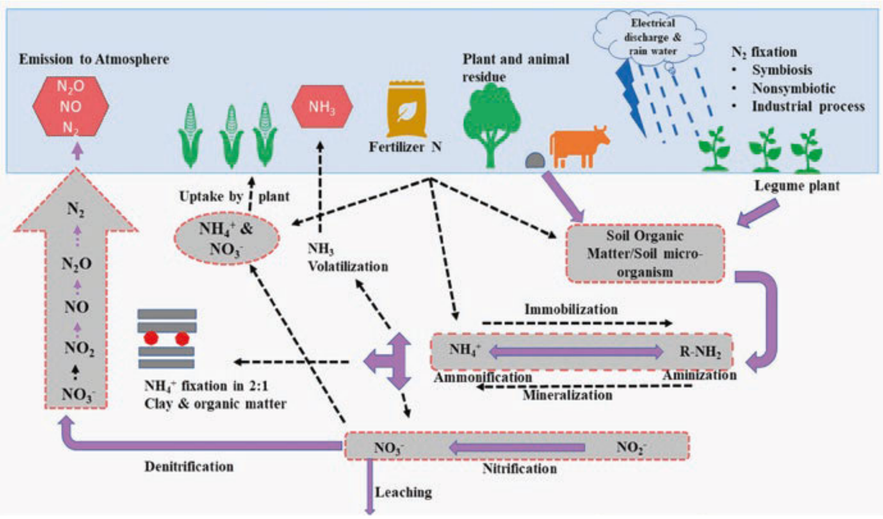


Fig. 7.1 The nitrogen cycle in soil systems

2.2 *Functions of Nitrogen in Plants*

The fact that nitrogen is essential for plants was discovered by Theodore de Saussure in 1804, and it was thus classified as one of the primary nutrients required for plant growth and development. Plants contain 1–6% nitrogen on the basis of weight; this proportion differs from plant to plant and from variety to variety. Nitrogen is an important component of proteins (which provide the basic framework for chloroplasts, mitochondria and other structures, including those involved in biochemical reactions), amino acids, nucleic acids, porphyrins, purines, pyrimidine nucleotides, enzymes, coenzymes and alkaloids. Nitrogen-containing chlorophyll is able to produce food materials such as carbohydrate in the presence of solar energy and CO_2. It is also responsible for transferring the genetic code from parents to progeny because nitrogen is a constituent of nucleic acids such as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). Application of nitrogenous fertilizer improves the quality of leafy vegetables and fodder crops.

2.3 *Nitrogen Status in Indian Soils*

In India, tropical and subtropical climates are dominant. However, Indian soils are poor in organic matter content and low in nitrogen. The total nitrogen content in Indian soils varies from 0.02% to 0.44%. The total nitrogen content in soil is affected by several soil factors and other climatic factors such as soil type, soil texture, soil pH, soil redox potential, rainfall, temperature, topography, vegetation and fertilizer management practices. The nitrogen status in different locations worldwide and in different parts of India are shown in Tables 7.2 and 7.3.

Table 7.2 Total soil nitrogen status in different locations worldwide

Location	Soil nitrogen (%)
New Zealand	2.38
UK	1.57
Japan	0.51
Austria	0.48
Pakistan	0.39
USA	0.38–0.70
West Africa	0.36
Argentina	0.2
Canada	0.2
Spain	0.1

Table 7.3 Total soil nitrogen status in different states and territories in India

State or territory	Soil texture	Nitrogen (%)
Uttarakhand	Silty clay loam	0.128
Assam	Loam	0.118
Andaman and Nicobar Islands	Sandy loam	0.114
Gujarat	Clayey	0.083
Haryana	Clayey	0.083
Himachal Pradesh	Silty clay loam	0.076
Delhi	Clayey	0.062
Orissa	Loam	0.058
West Bengal	Silty clay loam	0.053
Maharashtra	Clayey	0.045
Uttar Pradesh	Sandy loam	0.04
Punjab	Loam	0.031
Karnataka	Sandy loam	0.026
Rajasthan	Sandy clay loam	0.024

3 Nitrogen Sources for Crops

No nitrogen-containing minerals are found in soil. Plant production is therefore totally dependent on organic matter in soil as a source of nitrogen, which can be converted from plant residue, soil flora and soil fauna after their decomposition by the action of certain microorganisms. Bulk organic manure and concentrated organic manure (i.e. farmyard manure, compost, vermicompost, green manure, blood meal, meat meal and bone meal) are also sources of nitrogen, but concentrated manure is not practically applicable on a broad scale. The third important source of nitrogen is manufactured synthetic fertilizers, which are popularly used in the agriculture sector for maximizing crop production and have played a key role in the success of the green revolution, along with improved plant varieties and irrigation.

3.1 Crop Residue

Crop residue consists of those materials that are left over on agricultural fields after harvesting of the main crop. The residue materials may include stalks, stover, shells, stubble, stems, leaves, seed pods and other waste materials. In the 1960s, the green revolution was the major key factor in increasing food grain production in India while, at the same time, increasing production of other crops to fulfil the food demands of the growing human population (Fig. 7.2). In India, rice and wheat are the major staple foods, and their production has increased as the population as increased (Fig. 7.3).

As the production of different crops has increased, so has the amount of crop residue. The nitrogen content in different types of crop residue varies from 1% to 6%, and it also depends on the various components of the residue, such as straw and grain, whose nitrogen content varies. The nitrogen content in different crops and their various components are presented in Table 7.4.

All types of crop residue contain nitrogen fractions; ultimately, several kilograms of nitrogen are produced per tonne of crop residue. Figure 7.4 shows the nitrogen content in different types of crop residue.

3.2 Manure

Manure is a natural by-product of plants and animals, and it is mainly organic. Organic manure can be classified as either bulk organic manure or concentrated organic manure. Bulk organic manure is required in larger quantities to supply plant nutrients because it contains lower concentrations of nutrients than concentrated organic manure does. Bulk organic manure mainly consists of farmyard manure,

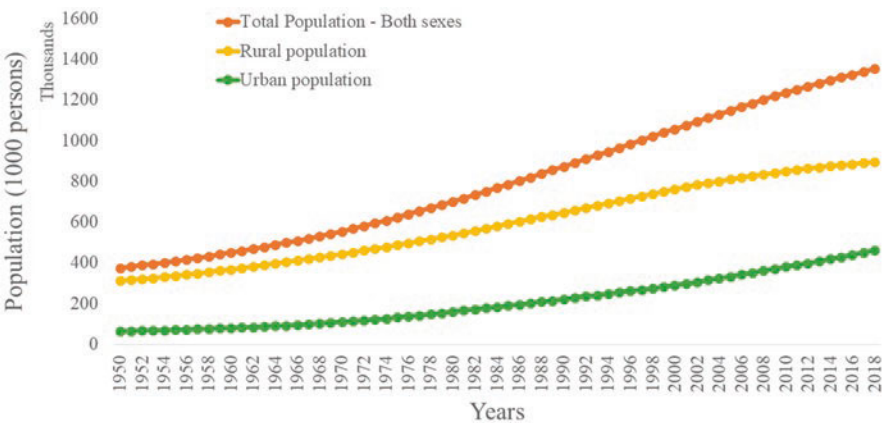


Fig. 7.2 Rural and urban population strength of India

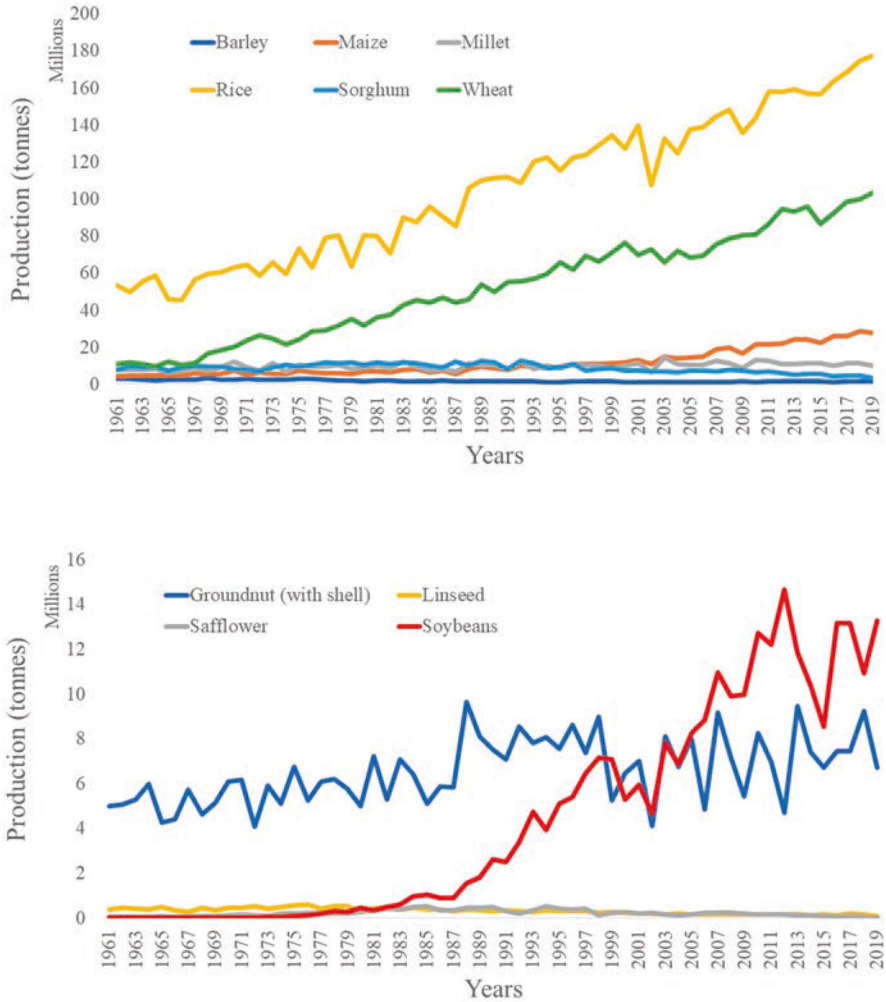


Fig. 7.3 Temporal changes in production of different crops in India

compost, night soil and green manure crops. Concentrated organic manure includes edible oil cake (groundnut cake), non-edible cake (neem, castor and mahua oil cake), blood meal, bone meal, fish meal etc. Most bulk organic manure has a 0.5–1% nitrogen content. The nitrogen contents of different types of concentrated organic manure are listed in Table 7.5.

The nitrogen content in dung varies between different animal species: dairy cattle produce 4.53, feeder cattle 5.40, poultry 13.54, swine 5.84, sheep 10.42 and horses 66.75 of nitrogen per tonne of fresh dung. The main source of dung is animal rearing. The quantity of dung produced and its nutrient content depend on various factors such as the season of the year, the feeding materials used and the type, age

Table 7.4 Nitrogen content in different types of crop residue and grain

Crop	Nitrogen (%)	
	Straw/stover/residue	Grain
Barley	0.683	2.112
Buckwheat	0.759	1.965
Corn: popping	0.970	2.047
Corn: dent	0.983	1.643
Groundnut	1.643	4.290
Millet	0.678	2.216
Oats	0.676	2.048
Rice	0.704	1.407
Sorghum	0.768	1.959
Soybean	0.786	6.535
Wheat	0.611	2.432

Source: Lal (2009)

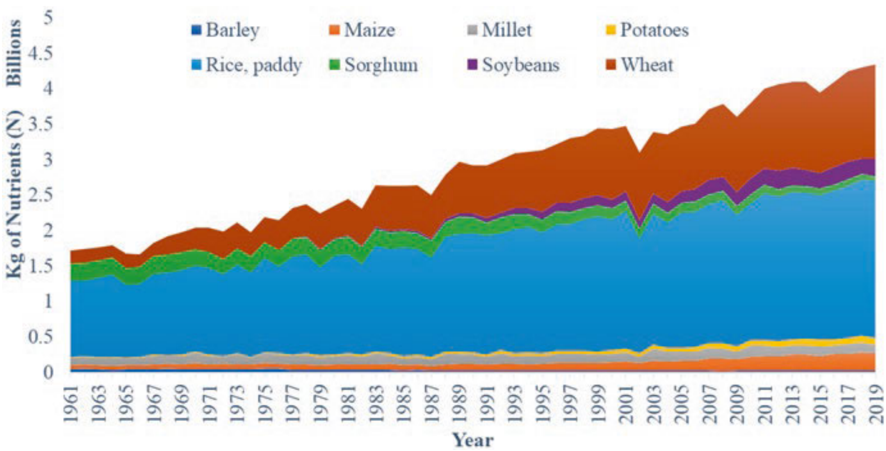


Fig. 7.4 Crop residue nitrogen content, expressed in kilograms of nutrients

and working category of the animals. India is home to large farm animal populations—mainly buffaloes, dairy cattle, non-dairy cattle, poultry, goats and sheep. Figure 7.5 shows the changes in farm animal populations from 1961 to 2019. The cattle non-dairy is more populated after the chicken, and they produce larger quantities of dung than chickens.

Not all of the nitrogen content in freshly produced animal excreta is retained when it is subsequently used as manure, because some of the nitrogen is lost during various processes, from handling to manure making and application in the field. In India, most of the nitrogen content in animal excreta is lost via the manure left on pastureland because open grazing systems are predominant in India; thus, not all of the excreta can be collected and used for manure preparation. Other losses of

Table 7.5 Nitrogen content in different types of concentrated organic manure

Product	Nitrogen (%)
Plant-origin products	
Edible oil cake	
Safflower (decorticated)	7.9
Groundnut	7.3
Sesame	6.2
Rapeseed/mustard	5.2
Linseed	4.9
Non-edible oil cake	
Neem	5.2
Castor	4.3
Cottonseed (decorticated)	3.9
Karanj	3.9
Mahua	2.5
Animal-origin products	
Blood meal	10–12
Meat meal	10–11
Guano	7–8
Fish meal	5–8
Bone meal (raw)	3.0

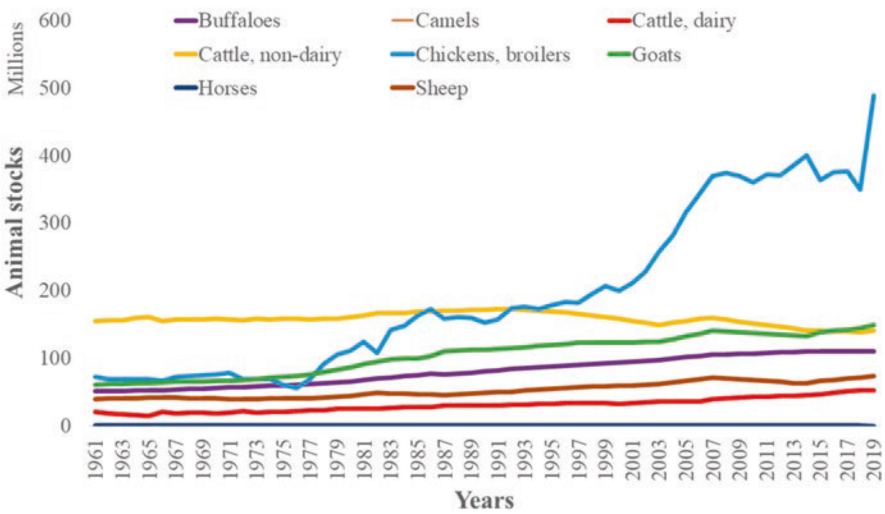


Fig. 7.5 Temporal changes in farm animal populations in India

nitrogen content from manure occur through leaching, through volatilization and during manure preparation. When manure is applied to soil or left on pastureland by animals, it comes into direct contact with sunlight, which stimulates loss of its

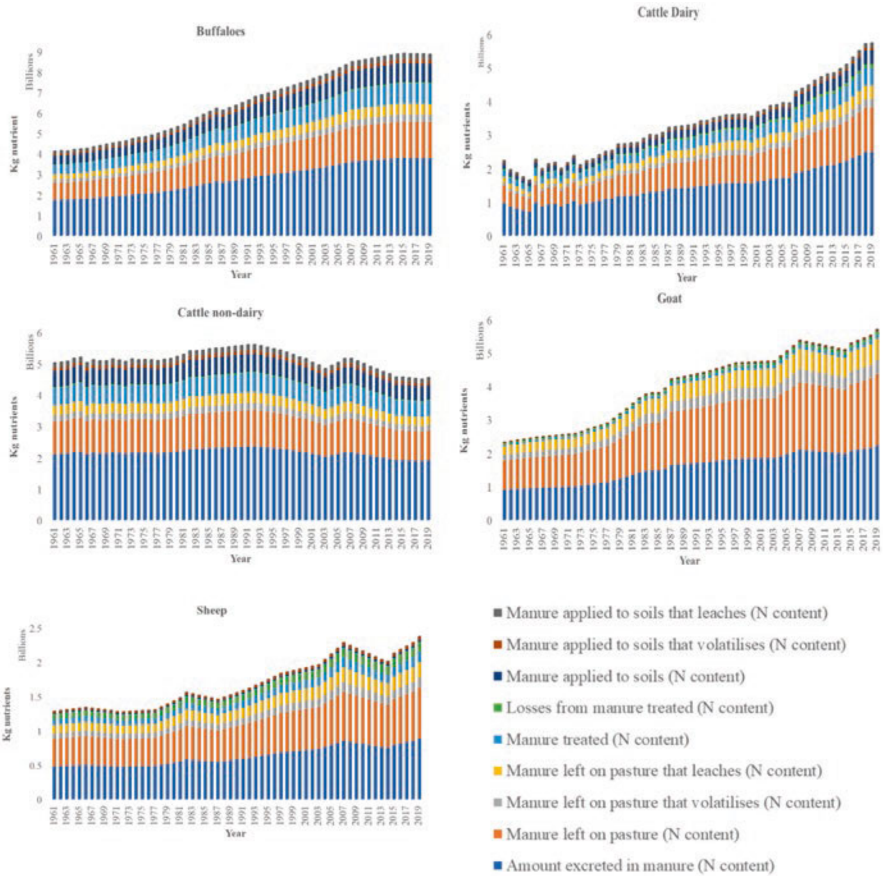


Fig. 7.6 Losses of nitrogen from excreta produced by different types of livestock

nitrogen content. The different amounts of nitrogen content lost from the excreta produced by the major types of livestock animals are depicted in Fig. 7.6.

3.3 Fertilizers

A fertilizer is a synthetic substance—either biological (biofertilizer) or chemical (straight and complex fertilizers)—that supplies essential nutrients to plants in order to improve their growth and productivity. Chemical nitrogenous fertilizers are classified into two types on the basis of their content of three primary nutrients: nitrogen, phosphorus and potassium (NPK). In straight nitrogen fertilizer, nitrogen is the only primary nutrient that is present; in complex nitrogen fertilizer, all three primary nutrients are present. Table 7.6 shows the content of nitrogen and other nutrients in different types of fertilizer.

Table 7.6 Nitrogen content in different types of chemical nitrogenous fertilizer

Fertilizer		Nitrogen (%)	Other specifications
Name	Chemical formula		
Ammonium chloride	NH_4Cl	25	2% chloride other than NH_4Cl (NaCl) [maximum]
Ammonium nitrate	NH_4NO_3	34	7.5% NH_4, 7.5% NO_3
Ammonium phosphate sulphate	–	16	20% P_2O_5, 15% S
Ammonium phosphate sulphate nitrate	–	20	20% P_2O_5, 15% S
Ammonium sulphate	$(NH_4)_2SO_4$	20.5	23–24% S
Anhydrous ammonia	NH_3	82	Maximum oil content 20 parts per million
Aqueous ammonia	–	20–25	Liquid fertilizer
Calcium ammonium nitrate	$NH_4NO_3 + CaCO_3$	25	8.1% Ca, 4.5% Mg
Calcium nitrate	$CaNO_3$	15	34% CaO
Diammonium phosphate	$(NH_4)_2HPO_4$	18	46% P_2O_5
Potassium nitrate	KNO_3	13	44% K_2O, 0.5% CaO, 0.5% MgO, 0.2% S, 1.2% Cl
Sodium nitrate	$NaNO_3$	16	26% water-soluble Na, 0.6% Cl
Urea	NH_2CONH_2	46	1.5% biuret (maximum)
Urea ammonium phosphate	–	28	28% P_2O_5
Urea ammonium phosphate	–	20	20% P_2O_5

Fertilizer is an important input for crop production in India. It supplies additional nutrients that are essential for growth and development of plants during their life cycle. During the green revolution, food grain production increased dramatically. The major factors responsible for the positive impacts of the green revolution were improvements in crop varieties, improvements in irrigation practices and methods, and fertilizer use. Farmers' demands for crop fertilizers increased in tandem with the increase in the production of nitrogenous fertilizers, as shown in Fig. 7.7. Between the green revolution and 2019–2020, the production of straight nitrogen fertilizers in India increased from 152,200 tonnes to 11,423,600 tonnes.

Among all nitrogenous fertilizers, urea is the one most widely produced and used for agricultural purposes in India. As shown in Figs. 7.8 and 7.9, production and agricultural use of urea fertilizers have grown incrementally in India over the past two decades.

3.4 *Biofertilizers*

Biofertilizers contain living microorganisms, which have the ability to perform biological processes (such as nitrogen fixation) that convert nutrients from forms that plants cannot use into forms they can use. Nitrogen-fixing biofertilizers are broadly

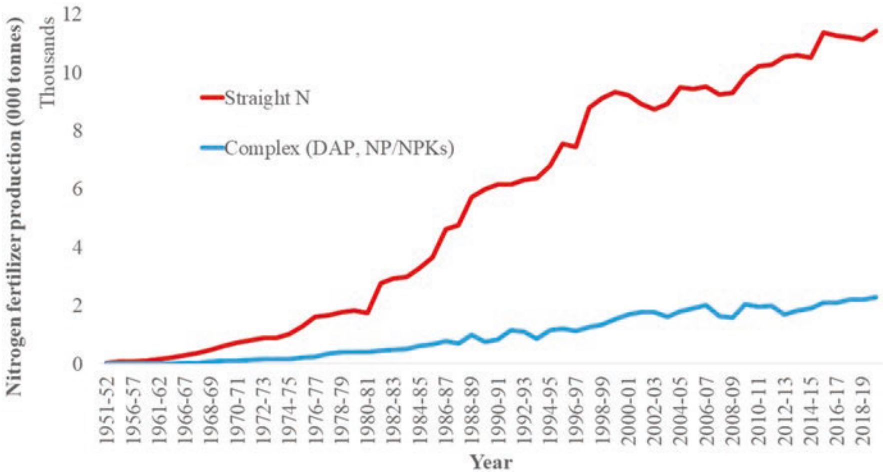


Fig. 7.7 Production of straight and complex nitrogenous fertilizers in India

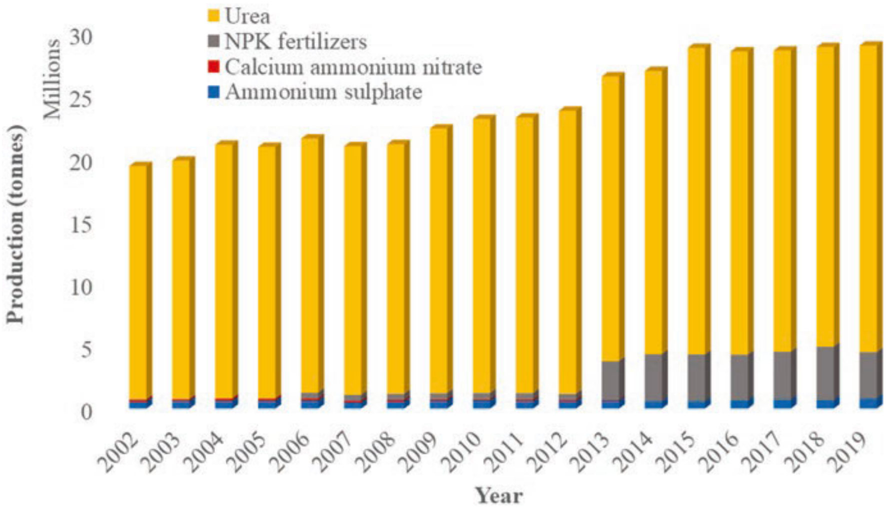


Fig. 7.8 Temporal changes in production of different nitrogenous fertilizers in India

classified into symbiotic and non-symbiotic nitrogen fixers. In symbiotic nitrogen fixation, the plant provides food material for the microorganisms and the microorganisms provide nutrients for the plant; thus, they are mutually beneficial without causing any harmful effects on each other. Some microorganisms fix atmospheric nitrogen in either plant roots (e.g. *Rhizobium* spp.) or plant stems (e.g. *Sesbania* spp.), whereas non-symbiotic microorganisms (e.g. *Anabaena*, *Azotobacter*, *Azospirillum*, *Beijerinckia*, *Clostridium* and Cyanobacteria) are able to fix nitrogen in their own bodies. Table 7.7 lists different nitrogen-fixing biofertilizers and suitable host crops for their use.

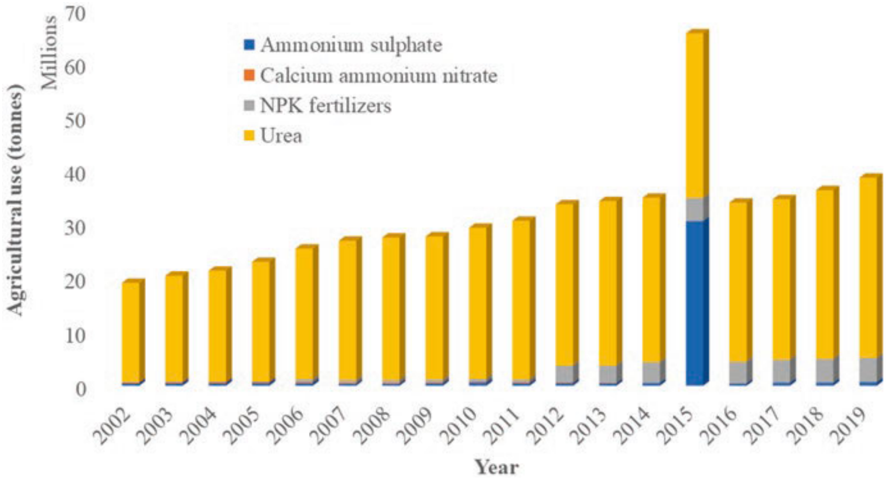


Fig. 7.9 Temporal changes in agricultural use of different nitrogenous fertilizers in India

Table 7.7 Modes of nitrogen fixation and suitable host crops for different types of biofertilizer

Biofertilizer	Mode of nitrogen fixation	Host crops
Azolla	Symbiotic	Rice
Azospirillum	Associative	Barley, maize, millet, oat, rice, sorghum, sugar cane etc.
Azotobacter	Non-symbiotic	Cereals (e.g. millet), cotton and vegetables
Cyanobacteria	Non-symbiotic	Rice
Rhizobium	Symbiotic	Legumes: groundnut, pulses and soybean

Many crops can themselves fix atmospheric nitrogen naturally in the soil, thereby increasing crop productivity without incurring fertilizer costs for farmers. For example, soybean crops can fix 105 kg/ha/year of nitrogen, and groundnut crops can fix 42 kg/ha/year.

4 Nitrogen in Soil

Although different sources of nitrogen can be applied to soil in order to provide the nitrogen that plants need to complete their life cycle, the nitrogen does not become available to the plants immediately after application to the soil. More time is needed to convert the nitrogen into forms the plants can use (i.e. NH_4^+ and NO_3^-). Three different processes involved in these conversions are described briefly in the following subsections.

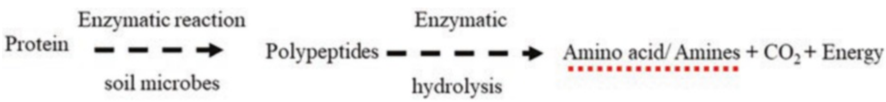
4.1 *Mineralization of Organic Nitrogen*

Mineralization can be defined as conversion of organic nitrogen from protein to the inorganic nitrogen forms NH_4^+ and NO_3^- (in the presence of certain microorganisms), which are then absorbed by plant roots. The organic N presence in the added crop residue and all the form of manures, mineralization process is faster when easily decomposable matter is present in the soil. This depends on the carbon-to-nitrogen (C:N) ratio of the materials in the soil. Mineralization occurs when the C:N ratio is <30:1, but when it is >30:1, nitrogen immobilization occurs because inorganic nitrogen is actually consumed by microorganisms during decomposition of organic nitrogen. When ligneous material is present in the soil, mineralization occurs more slowly because ligneous material is hard in nature and has a high C:N ratio.

The process of mineralization may include several subprocesses such as aminization, ammonification and nitrification.

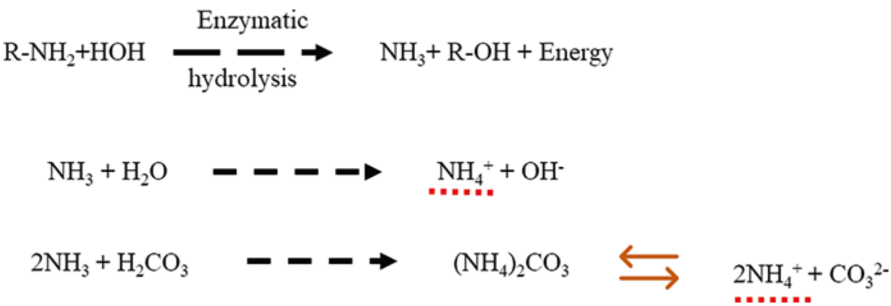
4.1.1 Aminization

This is the first step in the mineralization process. It involves conversion of proteins to amines and amino acids in the presence of certain microorganisms.



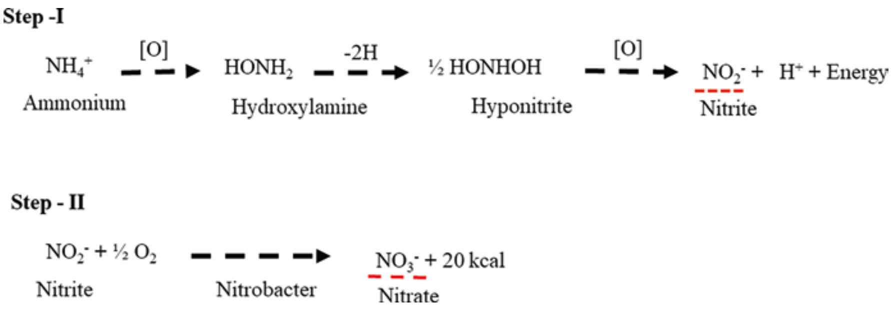
4.1.2 Ammonification

The second step in the mineralization process is ammonification, in which amino or amines are transformed into ammonium ions with the help of some aerobes and anaerobic bacteria. NH_4^+ is thereby made available for plant uptake, and this process increases the soil pH through production of OH^-. After plant uptake, the remaining ammonium ions are further utilized in the nitrification process.



4.1.3 Nitrification

Nitrification is an enzymatic oxidation process that converts ammonium ions into nitrate ions. It can be categorized as a two-step process. In the first step, NH_4^+ is converted into NO_2^- with the involvement of *Micrococcus*, *Nitrogela, Nitrosomonas* and *Nitrospira* bacteria. In the second step, NO_2^- is converted into NO_3^- by *Nitrobacter* and *Nitrocystis bacteria.* Nitrification is an acid-producing process in which H^+ ions are generated, causing soil acidity.



5 Nitrogen Conversion After Fertilizer Application

After application of nitrogenous fertilizer, nitrogen is converted into the plant-available forms of nitrogen NH_4^+ and NO_3^- (Fig. 7.10). Urea is the most widely used nitrogenous fertilizer in India; therefore, we focus here on the reaction of applied urea in soil. Urea is hydrolysed (i.e. it reacts with water molecules) and converted into ammonium carbonate; ultimately, two molecules of NH_4^+ are formed in reaction 1. Reaction 2 is similar to reaction 1 except that ammonium carbamate is formed instead of ammonium carbonate. The converted ammonium ion taken by the plants and remaining ammnium ions are futher utilized for nitrification process from applied urea fertilizer. Hydrolysis of urea increases the soil pH through production of OH^-.

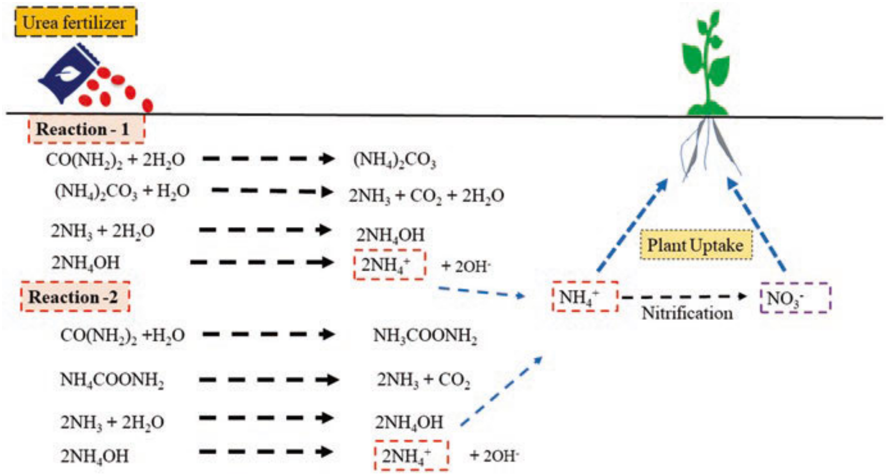


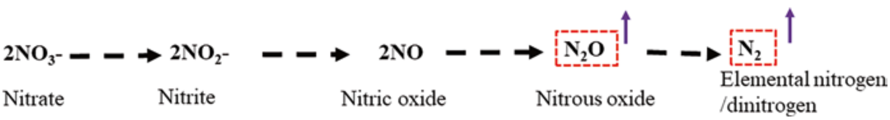
Fig. 7.10 Reaction of urea fertilizer in soil

6 Nitrogen Losses

In the soil system, gains and losses are equilibrated, but the present situation of intensive agriculture overexploits the available soil nitrogen; therefore, nitrogen is depleted in Indian soils. Various processes are involved in increasing soil nitrogen levels, such as nitrogen fixation through symbiotic and non-symbiotic associations. Nitrogen is lost from the soil system through denitrification, decomposition, volatilization and other processes. Leaching, crop removal, erosion and runoff aggravate nitrogen loss from the soil (Fig. 7.11).

6.1 Denitrification

Denitrification is a reduction process, occurring in oxygen-depleted soil, in which the N_2 and N_2O forms of nitrogen are lost from the soil to the atmosphere after conversion from the nitrate (NO_3^-) form.



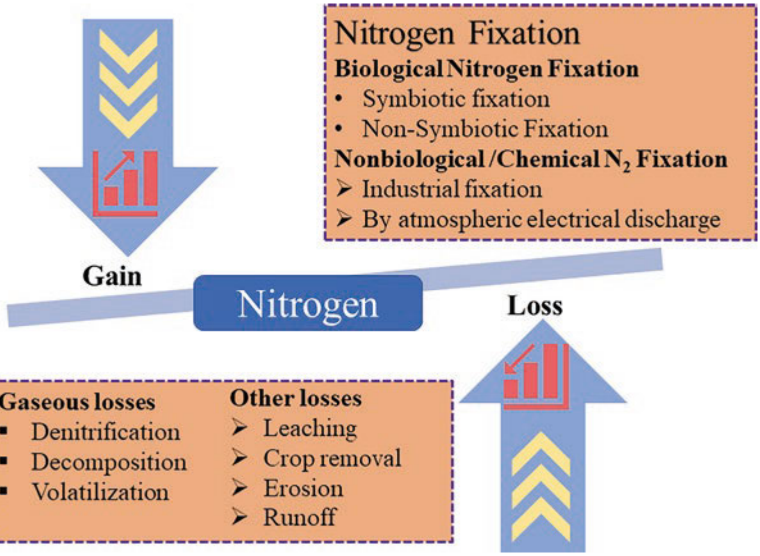
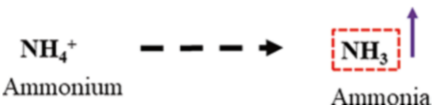


Fig. 7.11 Nitrogen gains and losses in soil

6.2 Volatilization

Gaseous loss of nitrogen in the form of ammonia (NH_3) from ammonium ions is called volatilization loss of nitrogen. It generally occurs during surface application of ammonium or urea fertilizer to high-pH soil at high temperatures.



6.3 Leaching

Nitrate ions are most susceptible to leaching loss, which occurs in high-rainfall conditions where sufficient water is available to leach the NO_3^- content out of the soil. The percolating water is able to move nitrate from the soil to the groundwater. The resulting high nitrate content pollutes the groundwater, making it unsuitable for drinking and irrigation. Figure 7.12 shows the leaching and volatilization losses that occur after application of nitrogenous fertilizers to soil. These losses have increased proportionately with the increasing use of fertilizer application in India.

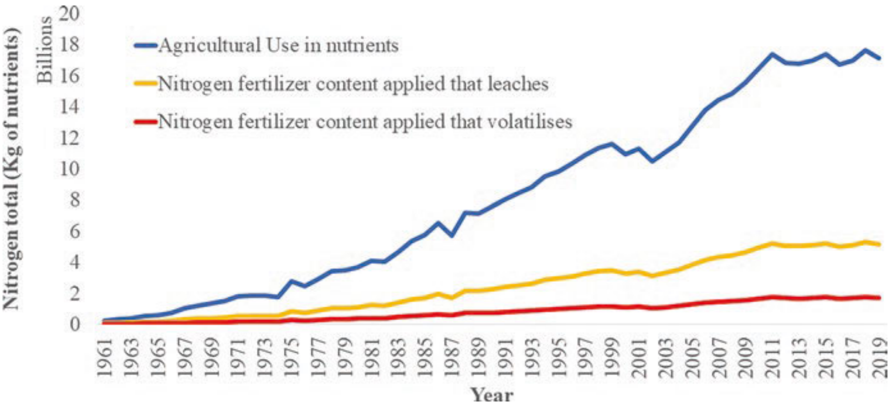


Fig. 7.12 Use of nitrogenous fertilizers and loss of soil nitrogen through leaching and volatilization

7 Nitrogen Pollution

Nitrogen that is lost from soil through various processes—such as denitrification, volatilization, leaching, runoff and erosion—remains in the environment and ultimately has direct or indirect harmful effects on humans, animals and plants. Since the green revolution, increasing quantities of synthetic fertilizers (especially nitrogenous fertilizers) have been used to optimize farm yields. The 'nitrogen budget' represents the contributions of different sources of nitrogen in the soil–atmosphere system (Fig. 7.13). Whereas, the nutrient budget of synthetic fertilizer jumped after the green revolution and securing first position with increasing continuously. Another perspective is that the nutrient budget for synthetic fertilizers is greater than the amount accounted for by crop removal, showing that the entire amount of nitrogen applied in fertilizer is not taken up by crop plants. This means that some of that nitrogen either remains in the soil system through NH_4^+ fixation or is lost via volatilization into the atmosphere, leaching, runoff and other types of loss.

7.1 Atmospheric Pollution

Most parts of the nitrogen transformation process, such as denitrification, release N_2O from various organic and inorganic sources of nitrogen. The average concentration of atmospheric nitrous oxide is approximately 310 ppbv, which represents an 8% increase from the pre-industrial era, and it is increasing by 0.2–0.3% annually. N_2O is also a global warming gas and plays a key role in climate change; this limits the cropping choices for production of food grains. The potency of N_2O gas in causing global warming is huge—310 times that of CO_2 and CH_4—and it has a long atmospheric lifespan of 114 years. Various agricultural practices with respect to

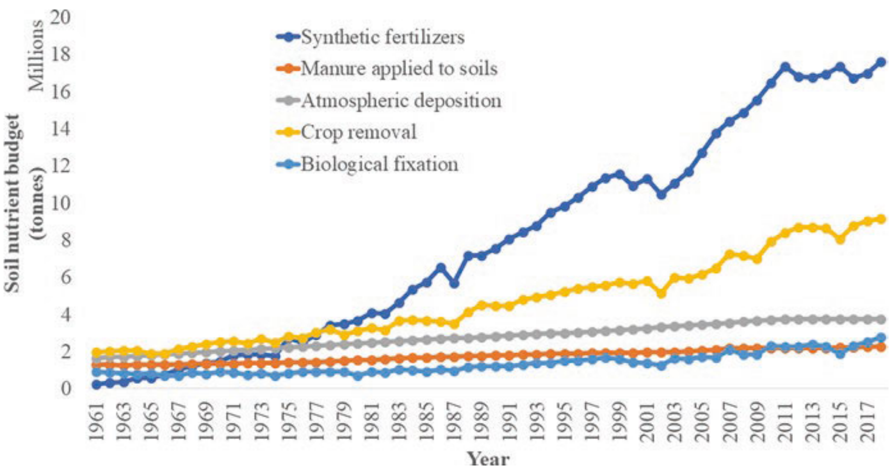


Fig. 7.13 Temporal changes in the total nitrogen budget in India

nutrient management are involved in N_2O emission. As shown in Fig. 7.14, synthetic fertilizer has been the dominant contributor to atmospheric emissions of N_2O gas since the 1990s, as compared with manure left on pastureland.

Global warming is expected to reduce crop production in India by 10–40%. The predicted increase in temperature of 1.5 °C and the predicted reduction in precipitation of 2 mm will reduce the rice yield by 3–15% and the wheat yield by 6–23% by 2050, and will reduce the wheat yield by 15–25% by 2080. The changes in annual temperature from 1961 to 2019 are presented in Fig. 7.15, which clearly shows that in the last 10 years, the average temperature has increased by 0.4–1.0 °C. These changes are due to increasing emissions of global warming gases, which adversely affect various climatic factors and ultimately affect crop production.

7.2 Groundwater Pollution

Nitrogen pollutes groundwater as a consequence of application of large amounts of fertilizer to soil and nitrate (NO_3^-) formation due to conversion of nitrogen. Nitrogen is not stable in soil for long periods; it moves throughout the soil profile with percolating water that mixes with groundwater. When groundwater with enriched NO_3^- content (NO_3^- >10 parts per million (ppm)) is used continuously for drinking purposes, it may cause methemoglobinemia disease in humans, which is also known as 'blue baby syndrome'. The common symptoms of blue baby syndrome generally appear in 6-month-old babies, whose nails, eyes and skin show a bluish colour due to nitrite absorbed by the blood (nitrate is converted into nitrite after consumption).

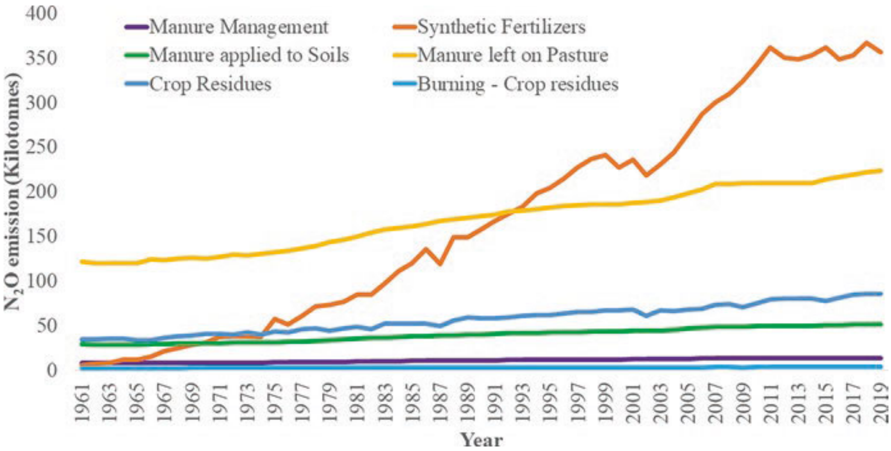


Fig. 7.14 Nitrous oxide emissions from different agricultural practices in India

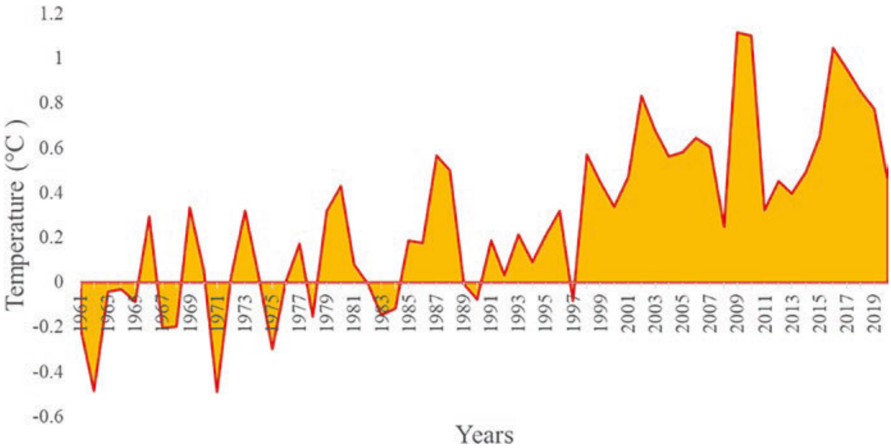


Fig. 7.15 Temporal changes in temperature in India

In India, the major dominant states that were key pillars for the success of the green revolution were mainly in northern India (Haryana, Punjab and Uttar Pradesh), where nitrogenous fertilizers were applied heavily to increase yields of food grains such as rice and wheat. The positive results of nitrogenous fertilizer application encouraged more farmers to use even greater quantities of fertilizers. The increase in use of those fertilizers promoted NO_3^- losses through leaching and groundwater pollution, making the water unsafe for drinking and for soil and plants. Table 7.8 showed that the nitrate content in ground water of different location was exceeding the limits (> 50 mg/l) which may harm human health when it consumed continuously as a drinking water.

Table 7.8 Nitrate (NO_3^-) concentrations in water samples from different locations in northern India

Territory or state	Region	NO_3^- (mg/l)	Reference
Delhi	Gadaipur (Mrhrauli block)	743	Majumdar and Gupta (2000)
	Kanganhari (Najafgarh block)	300	
	Palla (Alipur block)	277	
	Kanjhawala	140	
	Ghazipur (Shahdara)	139	
Uttar Pradesh	Varanasi	Northern: 342, central: 199, southern: 100	Majumdar and Gupta (2000)
	Raebareli	Pre-monsoon: 0–139.8, monsoon: 0–164.3, post-monsoon: 0–123.4	Shukla and Saxena (2020)
	Kanpur	28–82	Sankaramakrishanan et al. (2008)
	Varanasi	4–110	Raju et al. (2009)
Punjab	South Punjab	38.45–198.05	Ahada and Suthar (2018)
	Semi-arid region	2.98–78.76	Chaudhry and Sachdeva (2020)
Haryana	Sonipat	12.47–127.80	Sheikh et al. (2017)
	Panipat	0.5–69	Kaur et al. (2020)

7.3 Eutrophication

Eutrophication is different from groundwater pollution; it occurs when surface water becomes over-enriched with nutrients (particularly nitrogen and phosphorus), promoting growth of algae, plankton and biomass in surface water bodies. Oxygen requirements are increased by decomposition of the increased biomass, which is harmful for other organisms living in the affected water bodies.

8 Conclusions

The population of India is increasing dramatically without a simultaneous increase occurring in the availability of land. Efforts have therefore been made to maximize food grain production to supply the food demands of the growing population, and consumption of nitrogenous fertilizer has therefore increased to produce more food grain. However, most applied nitrogenous fertilizer has had poor efficiency because only small quantities of nitrogen are taken up by crops and most of the nitrogen is lost through various process such as denitrification, volatilization, leaching and surface runoff. The lost nitrogen persists long term in the environment (in the forms of N_2O, NO and NH_3 in the atmosphere and NO_3^- in groundwater) and damages the health of human beings. Heavy application of fertilizer increases farmers' input costs, the risk of uncertainty and environmental degradation. Therefore, integration of various natural nitrogen sources (such as manure, biofertilizer and crop residue) with fertilizer to provide supplemental nitrogen is preferable to application of fertilizer alone and is more beneficial for the environment.

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Part III
Advanced Technology in Agriculture for Smart Faming

Chapter 8
Resilience Against Salt Tolerance in Rice Cultivars, Using Various Strategies of Conventional Breeding, Molecular Breeding and Transgenic Approaches

Ashutosh Singh and Alok Kumar Singh

Abstract Salinity (an excessive quantity of soluble salts in the soil solution) is one of the major stresses that limit the yield production of rice. Soil salinization has become one of the key environmental problems affecting rice growth and productivity worldwide. Soil irrigated with well water may also show unavailability of water induced by salinity in the field, which decreases the osmotic potential of soil solutes and thus makes it difficult for roots to extract water from the surrounding media. Breeding of salt-tolerant rice genotypes is one of the most effective and long-term solutions for resource-poor farmers in salt-prone areas. One of the salt-tolerant rice cultivars, popularly known as Pokkali, has a major quantitative trait locus (*Saltol*) identified on chromosome 1, which is involved in salinity tolerance at the seedling stage of the crop. Progress and developments in DNA marker technology, especially in rice-breeding programmes, permit us to improve the timing and accuracy of the breeding programme where pronounced effects of the environment lead to poor selection efficiency.

Keywords Salinity · Salt tolerance · Saltol · DNA marker · Transgenic

1 Introduction

Cereals are major grain-yielding crops frequently grown across the world, and they are exposed to several different types of biotic and abiotic stress that severely affect their growth and yield. Of these stresses, salinity is one of the more challenging abiotic stresses. It directly affects crop production in both irrigated and rainfed areas

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_8

across the world, and it results in poor crop yields (Singh et al. 2011). Soil salinity is a huge environmental challenge worldwide, influences the sustainability of agriculture and is increasing over time (Hossain et al. 2012). The increase in soil salinity is due to excessive use of chemical fertilizers, soil erosion, global warming, melting of ice caps and natural disasters that are causing widespread submergence of agricultural land under seawater (Brinkman 1980). The total land area affected by salinity worldwide was 323 million hectares in 1980 but is expected to exceed 400 million hectares by 2025. About 7–8.5% of the world's total land area is affected by salinity; this is a similar percentage to that occupied by arable land (Ghassemi et al. 1995; Szabolcs 1994). The total area affected by salinity is still increasing as a result of irrigation and land clearance (Flowers et al. 2000).

Salinity that occurs generally in areas with low rainfall is known as primary salinity. Evaporation or transpiration is the major cause of water loss, which continuously increases the salt concentration in the soil (McDowell 2008). Natural soil erosion is a major problem around the globe and is exacerbated by primary soil salinity (Hulsebusch et al. 2007). Salinity is also created by various human activities, including destruction of native vegetation through planting of shallow-rooted vegetation or through use of excessive amounts of chemical fertilizers during crop production. Inefficient distribution of water in irrigation for agricultural production is another cause of soil salinity and comes under the category of secondary salinity (Beresford et al. 2001; Rose 2004). Suppressed growth of plants is another consequence of different factors such as factorable osmotic potential effect and ion toxicity, which induce nutrient imbalances in soil (Abari et al. 2011).

According to Khush (1999), salinity is one of the major abiotic stresses that affect the production and quality of cereals across the world. Accumulation of soluble salts in cultivated land and high concentrations of sodium (Na^+), chloride (Cl^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), sulphate ($SO_4{}^{2-}$) and bicarbonate (HCO^{3-}) in soil are the major constituents that influence growth and development of crops and ultimately reduce maximum yields (Shahbaz and Ashraf 2007, 2013; Shahbaz and Zia 2011; Shahbaz et al. 2012, 2013; Ismail and Horie 2017). Bonilla et al. (2004) and Chinnusamy et al. (2005) have also reported that salinity alters the uptake and rates of absorption of all mineral nutrients, resulting in deficiency symptoms. Most toxic effects of NaCl are mainly due to Na^+ toxicity.

Control of movement of salt into and throughout plants and control of its specific effects on crop growth and development are prerequisites for salt tolerance. Salt tolerance can be achieved by changing farm management practices at certain levels, such as adoption of partial root zone drying methodology and drip irrigation or micro-irrigation to optimize use of water. Various agronomic patterns of farming, such as mixed cropping (alley farming and intercropping), phase forming (incorporation of perennials in rotation with annual crops) and site-specific farming, or precision farming, can also reduce the effects of soluble salt in soil (Ridley et al. 2001). Salt tolerance is usually assessed in terms of percentage biomass production in saline versus control conditions over a prolonged period of time.

Domestication of wild salt-tolerant species, conventional breeding, tolerant species, tissue cultures and molecular biology are the basic strategies that exist for development of salt-tolerant plants (Shannon and Noble 1990; Shannon 1993; Quan et al. 2018). However, selection of high-yielding, salt-tolerant cultivars has proven to be an elusive target for plant breeders, and identification of reliable genetic markers for salt tolerance has been even more elusive for plant physiologists and molecular biologists. Some successes have been reported from studies on development of stress tolerance in cereals; conventional breeding, marker-assisted selection (MAS) and transgenic approaches are the most viable ones (Slafer et al. 1999; Araus et al. 2002; Liu et al. 2017). Testing of Australian wild rice accessions has enabled analysis of their growth responses to a range of salt levels (Yichie et al. 2018).

We have reviewed the literature on various approaches to conventional breeding, transgenic approaches, and selection of trait-specific tolerant sources for exclusion of Na^+, Cl^-, Mg^{2+}, Ca^{2+}, SO_4^{2-} and HCO^{3-}. Development of molecular markers and their potential utilization in marker-assisted breeding are based on sound physiological principles in producing salt tolerance in cultivated rice. Innovative technologies such as immunostaining and Na^+ tracer experiments have suggested that the OsHKT1;5 protein contributes to Na^+ exclusion in the phloem portion of the plants, in addition to xylem Na^+ unloading, to prevent Na^+ transfer to young leaf blades of the plants (Kobayashi et al. 2017).

2 Rice and Salinity

From the food security point of view, rice is one of the most important staple food crops in many countries. In India, rice is grown in irrigated, moderately irrigated, non-irrigated, upland, submerged and saline soil conditions. In 2013–2014, the land area used for rice growing in India was 44.136 million hectares, with production totalling 106.65 million tonnes. The cultivated type of rice (*Oryza sativa*) that has been spread throughout the world came originally from the Asian A-genome group of species in the genus *Oryza* (Chang 1976; Oka 1988; Wang et al. 1992; Khush 1999; Ge et al. 1999).

Rice is sensitive and susceptible to saline environments during both its vegetative and reproductive stages (Naheed et al. 2008; Shahbaz and Zia 2011). Production of rice is affected by salt stress, but some *indica* cultivars (such as Kalarata, Nona Bokra, FL478 and Pokkali) are tolerant of salinity (Yeo et al. 1990). Salinity tolerance is a complex trait, which involves many processes such as movement of sodium between shoots and roots, sodium discharge from roots and assimilation of sodium in vacuoles and older tissues (Thomson et al. 2007). Rice is well suited to various physiological, developmental, genetic and evolutionary studies because it has a well-defined genomic and physical map (Tao et al. 1994).

Rice has 12 (2*n*) chromosomes and a genome size estimated at 430 Mb (Arumuganathan and Earle 1991; Eckardt 2001; Sasaki and Burr 2000). The *indica* and *japonica* genomes have been sequenced completely (Londo and Chiang 2006). According to Garris et al. (2005) *japonica* emerged first, followed by *indica*. Several rice varieties have been developed for salinity tolerance and are recommended for

Table 8.1 Salinity-tolerant rice varieties recommended for cultivation in different agroclimatic zones in India

States	Recommended rice varieties
Andhra Pradesh	Amal Mana, Bhuthnath, CSR 10, CSR 13, CSR 27, Narendra Usar Dhan 2008, Sumati, Vikas
West Bengal	Amalmana, Bhuthnath, Sumati, Vikas
Odisa	Amal Mana, Bhuthnath, Narendra Usar Dhan 2008, Sumati
Maharashtra	Bhuthnath, CSR 13, CSR 27
Uttar Pradesh	CSR 10, CSR 13, CSR 23, CSR 27, Narendra Usar Dhan 2, Narendra Usar Dhan 3
Gujarat, Haryana, Punjab	CSR 10, CSR 13, CSR 23, CSR 27
Bihar, Jharkhand	CSR 13, CSR 27, Vikas
Kerala	CSR 23, CSR 27, Sumati, Vikas
Tamil Nadu	CSR 23, CSR 27
Madhya Pradesh	Vikas

cultivation in various agroclimatic zones in India. Farmers frequently grow these cultivars in saline soils (Table 8.1).

Various approaches to conventional breeding, molecular breeding and transgenics have been described in the literature and will be helpful for future research on development of salt-tolerant rice cultivars for national food security.

3 Conventional Approaches to Development of Salt-Tolerant Rice Cultivars

Conventional breeding is one of the traditional and classical approaches to development of new cultivars. It involves insertion of various desirable traits into different cultivars via simple plant-breeding techniques. In this setting, unavailability of salt-tolerant cultivars can be considered a major problem. Traditional crop breeding using salt-tolerant lines has been used to incorporate salinity traits into cultivated varieties. Development of salt-tolerant rice cultivars through conventional breeding has been done successfully by various researchers. In India, six salt-tolerant varieties have been developed through conventional breeding for cultivation in salt-affected soil (Singh et al. 2004).

According to Mishra et al. (2003), the Central Soil Salinity Research Institute (CSSRI) in Karnal, India, has developed 32 salt-tolerant rice varieties, including CSR 10, which is a rice cultivar intended for use in soils with high salt levels. Other genotypes—such as CSR 1, CSR 2, CSR 3, CSR 13, CSR 22, CSR 23, CSR 26, CSR 27 and SR 26 B—have been developed for cultivation in highly, moderately and coastal saline areas of India (Table 8.2). CSR 30 (also known as Yamani), a scented type of rice cultivar with moderate tolerance of salt stress, has been released for commercial cultivation by the Central Variety Release Committee of India

Table 8.2 Improvements in salt tolerance of rice crops, using conventional breeding approaches

Genotypes	Release source	Area of performance	References
CSR 10	Central Variety Release Committee of India	High salt levels	Singh et al. (2004) and Sankar et al. (2011)
CSR 13, CSR 27, Narendra Usar Dhan 2, Narendra Usar Dhan 3	Central Variety Release Committee of India	Moderate to high salt levels	Singh et al. (2004) and Sankar et al. (2011)
Basmati CSR 30	Central Variety Release Committee of India	Moderate salt stress	Singh et al. (2004) and Sankar et al. (2011)
CSR 1, CSR 2, CSR 3, CSR 22, CSR 23, CSR 26, CSR 27, CSR 30	Central Soil Salinity Research Institute, India	Coastal saline soil	Mishra et al. (2003)
Pokkali, Vytilla 1, Vytilla 2, Vytilla 3, Vytilla 4, Vytilla 5	Kerala Agricultural University, India	Coastal regions	Sankar et al. (2011)
BTS 24, Bhurarata, Kalarata, Panvel 1, Panvel 2, Panvel 3, SR 26 B	International Rice Research Institute, Philippines	Coastal regions	Sankar et al. (2011)
Mansarovar, Pavizham, Ponni, Salivahan, Savitri, Swarnadhan	International Rice Research Institute, Philippines	Shallow-water saline conditions	Sankar et al. (2011)
AD 85002, BR 10, Co 43, CSR 1, CSR 4, IET 8113, Patnai 23, PVR 1, PY 1, SR 26 B, TRY 1, TRY 2	International Rice Research Institute, Philippines	Saline area of Tamil Nadu	Sankar et al. (2011)

(Sankar et al. 2011). Narendra Dhan 2 and Narendra Dhan 3, which were developed by Narendra Deva Agricultural University in Faizabad for growth in highly saline soil, are now being used for reclamation of saline soil in Uttar Pradesh. Some rice cultivars—such as Bhurarata, BTS 24, Kalarata, Panvel 1, Panvel 2, Panvel 3 and SR 26 B—have been released by the International Rice Research Institute in the Philippines as salt-tolerant rice cultivars for cultivation in coastal regions of the world, as well as in India (Sankar et al. 2011). Other salt-tolerant cultivars of rice—such as AD 85002, BR 10, Co 43, CSR 1, CSR 4, IET 8113, Mansarovar, Patnai 23, Pavizham, Ponni, PVR 1, PY 1, Salivahan, Savitri, Swarnadhan, TRY 1 and TRY 2—are recommended for use in salt-affected areas and shallow-water salinity conditions in Tamil Nadu (Sankar et al. 2011). Thus, a huge number of salt-tolerant varieties have been developed through the conventional breeding approach, as shown in Table 8.2.

4 Molecular Breeding for Incorporation of Salt Tolerance in Rice Cultivars

Marker-assisted backcross breeding is the most powerful and durable approach to incorporation of salt-tolerant segments. Salinity is a multidimensional form of abiotic stress, and more than 30 quantitative trait loci (QTLs) are involved in salt tolerance mechanisms in the case of rice. Several mechanisms of salt tolerance at different crop stages have been studied for identification of the loci associated with these mechanisms, and several loci governing salt tolerance mechanisms have been identified from rice germplasms. These QTLs should be helpful for incorporation of salinity tolerance into commercially cultivated rice cultivars through marker-assisted backcross breeding approaches. Salt tolerance is a polygenic trait controlled by several QTLs (Ismail and Horie 2017). QTLs have been identified on rice chromosomes 1, 2, 3, 6 and 7; most of those involved in salt tolerance mechanisms in rice are located on chromosome 1 (Gong et al. 1999; Koyama et al. 2001; Bonilla et al. 2002; Akhtar 2002; Lin et al. 2004; Ren et al. 2005; Walia et al. 2005; Flowers et al. 2000).

Molecular markers have been used in chromosome-wide QTL studies of various ionic mechanisms of salt tolerance at different stages of rice cultivation. The QTLs qNAKUP-6 on chromosome 6 and qNAKUP-3 on chromosome 3 of the rice genome are associated with the Na^+/K^+ uptake ratio under saline conditions. The flanking markers RM3827–RM340 and RM6832–RM7389 have been used for germplasm screening and molecular breeding for incorporation of salinity tolerance (Sabouri and Sabouri 2008). Ming et al. (2005) studied the QTLs qNAK-2 and qNAK-6, located on chromosomes 2 and 6, for improving the Na^+/K^+ ratio for salt tolerance, using the markers RM318–RM262 and RM176–RM345, which are frequently distributed across chromosomes 2 and 6 of the rice genome.

The QTL *sqST-1*, located on chromosome 1, which confers salt tolerance at the seedling stage, was identified and screened out using the Est12–RZ569A flanking markers (Lee et al. 2007). Other markers such as simple sequence repeats (SSRs) and amplified fragment length polymorphisms (AFLPs) have been designed for the K^+/Na^+ locus on chromosome 1 and used successfully. SSRs located on chromosome 1 were used and demonstrated by Ren et al. (2005) in their experiment on K^+/Na^+ homoeostasis under saline conditions for germplasm screening using the markers QNa, QNa:K and SKC1/OsHKT8 in the flanking region of rice chromosome 1. In this context, Flowers et al. (2000) also used AFLPs (QNa, QK1, QK2 and QNaK) visualized on rice chromosome 1 for rice germplasm screening and foreground selection for improving Na^+, K^+ and discrimination of Na^+ for salt tolerance.

Single nucleotide polymorphisms (SNPs) for the Na^+/K^+ ratio, which is involved in a salt tolerance mechanism, are also available on chromosomes 1, 4, 6 and 7, and are helpful in SNP detection as well as in parental polymorphism surveying in marker-assisted backcross breeding for development of salt tolerance rice cultivars (Kumar et al. 2015). In rice, *saltol* is a major QTL for salt tolerance at the seedling stage, being associated with a low Na^+/K^+ ratio, high K^+ and low Na^+ adsorption, as studied by various researchers (Gregorio 1997; Akhtar 2002; Tumimbang et al. 2005). The *saltol* QTL is located on chromosome 1 of the rice genome, and markers for the flanking region have also been identified for validation and foreground selection in marker-assisted breeding (Bonilla et al. 2002). Walia et al. (2005) also states that the flanking markers Os01g20160, Os01g25280 related High K^+, low Na^+ Salt-induced gene for *Saltol* and *SalT* locus of chromosome 1 should must be validate the salt tolerance region and mapped based study for development of recombinants and near isogenic lines with respect to salt tolerance. The *saltol* QTL, identified in the salt tolerance rice cultivar Pokkali, is a robust QTL and was mapped on chromosome 1 by use of flanking markers RM23 and RM140 from 80 recombinant inbred lines (RILs) developed from a cross between rice-breeding lines IR29 (sensitive) and Pokkali (tolerant). In other cultivars, this QTL conferred phenotypic variation of 64–80% under different saline soil conditions (Bonilla et al. 2002).

Genotypes and traits/QTLs that are tolerant at more than one stage may exist and would be ideal for multidimensional salinity tolerance (Munns and Tester 2008). Thomson et al. (2010) experimented on 140 RILs developed from crosses of IR29/Pokkali, using more than 100 SSR DNA markers, and also validated the location of the *Saltol* QTL on chromosome 1. In another study by Naresh Babu et al. (2014), flanking markers RM8094 and RM3412, associated with Pokkali for salt tolerance, were used for validation of salt tolerance in rice cultivars. A QTL coding for an HKT-type transporter system controlling K^+ homoeostasis, named *SKC1,* was also identified by Ren et al. (2005) for adverse saline conditions and could be used for development of salinity tolerant cultivars of rice.

A parental polymorphism survey is one of the important strategies used in marker-assisted backcross breeding for incorporation of useful traits from donor to recipient lines. A molecular marker–based parental polymorphism survey for the validity and durability of salt tolerance in the case of rice could be achieved by use of many more markers across all 12 chromosomes of the rice genome, including flanking regions. Several markers have been designed for such a parental polymorphism survey and used by researchers in marker-assisted backcross breeding for incorporation of salinity tolerance at various crop stages (Gregorio 1997; Bonilla et al. 2002).

Most regions of chromosome 1 in rice have a locus for salt tolerance, and markers are also available for future study and development of salt-tolerant rice cultivars, using molecular breeding techniques. A huge number of salt-tolerant cultivars have been developed in rice through conventional breeding, but these are region specific because of the complex nature of soil composition and climatic conditions. Only a few varieties of rice—such as CSR 10, CSR 13, CSR 27, Narendra Usar Dhan 2, Narendra Usar Dhan 3 and Yamini—have been found to be salt tolerant in various kinds of salinity from the seedling stage to the crop establishment stage (Mishra et al. 2003). Marker-assisted breeding for salt tolerance in rice has been employed successfully. Many QTLs for salt tolerance have been identified and incorporated through MAS. The transgenic approach has been reported to be very effective for rice, with several genes involved in salt tolerance having been successfully incorporated into rice. According to the literature, transgenic approaches have also been employed to improve salt tolerance traits in other cereal crops such as barley, maize, oats, pearl millet and sorghum (Verma et al. 2007). Quan et al. (2018) developed a salt-tolerant line of Dongxiang/Ningjing 15 (DJ15) crosses under salt stress field conditions, using a population of salt-tolerant Dongxiang wild rice crossed with the cultivated rice variety Ningjing 16 (NJ16). A large number of QTLs and their molecular markers related to the flanking region have been identified in many rice cultivars for development of salt-tolerant cultivars through marker-assisted backcross breeding, and these will definitely be helpful in future breeding programmes (Table 8.3).

5 Transgenic Approaches to Salinity Tolerance in Rice

This is a marvellous approach to crop improvement, achieved by insertion of a foreign gene. Transgenic and genetic engineering approaches have been used by different researchers for development of salt-tolerant rice varieties with durability of tolerance (Table 8.4). Genes for vascular Na^+/H^+ transporters from various sources have been incorporated into rice through genetic engineering for salinity tolerance (Ohta et al. 2002; Zhao et al. 2006). According to Ohta et al. (2002), incorporation of the vacuolar Na^+/H^+ antiporter *AgNHX1* gene from *Atriplex gmelinii* into rice improved survival (by 50% or 80–100%) under saline conditions at the seedling to vegetative stages of the rice crop. Another gene system—a vacuolar Na^+/H^+ antiporter gene *PgNHX1* isolated from *Pennisetum glaucum* (L.)—was incorporated into rice, using a transgenic approach, to achieve durable salt resistance. This resulted in a well-developed root system, with 81% greater shoot and root lengths (Verma et al. 2007). Another genetic engineering study to incorporate high accumulation of Na^+ and low K^+ for tolerance of salinity levels of up to 0.2 M, using a wild rice cultivar with special reference to the vacuolar Na^+/H^+ antiporter gene *OsNHX*, was conducted by Fukuda et al. (2004).

The yeast Na^+/H^+ antiporter *SOD2* gene was transferred into rice through genetic engineering and performed well in sodic soil (Zhao et al. 2006). Another trehalose gene from yeast (*TPS1* and *TPSP-Ubi1*) showed not only tolerance of salt but also enhanced drought and cold tolerance (Garg et al. 2002; Jang et al. 2003).

Over-accumulation of the biochemical proline is an important screening criterion for salt tolerance. Proline is known to be released by plants under environmental conditions that are unfavourable for proper growth and development, and it helps them cope with acute stress conditions. In this context, the gene *P5CS* obtained from moth bean (*Vigna aconitifolia*) was shown to be over-expressed in rice in saline and non-saline conditions (Su and Wu 2004). Su and Wu (2004) found that shoot fresh weight was increased by 30–93% and root fresh weight 37–74% in transgenic rice plants exposed to less than 200 mM NaCl, in comparison with their wild-type relatives.

Over-accumulation of glutamate and glutamine under acute saline conditions may provide survival stamina for crops, and this can be achieved with help from the

Table 8.3 Identified quantitative trait loci (QTLs) involved in salt tolerance mechanisms and used in marker-assisted breeding

Traits	QTLs	Chromosomes	Flanking markers	References
Survival days in salt	*Std*	1	RG612–C131	Gong et al. (1999)
Shoot K^+ concentration, total shoot Na^+, shoot Na^+/K^+ ratio	–	1	E12M46-6–E12M48-6, E12M46-7–R886, E12M46-7–R886	Koyama et al. (2001)
Shoot Na^+ and K^+	*Saltol*	1	Saltol (between C52903S, C1733S) and RM140–C1733S	Gregorio (1997)
Shoot Na^+ and K^+	–			Bonilla et al. (2002)
Na^+, K^+/Na^+ ratio	*Saltol*	1	RZ276–RG811	Akhtar (2002)
Shoot K^+ concentration, root Na^+, total survival days	*qSKC QRNTQ-1*	1	C1211–S2139, C1370–C86	Lin et al. (2004)
	QSDS-1		C813–S13312	
Shoot K^+ concentration	*SKC1*	1	K036–Pr in PAC clone AP003567	Ren et al. (2005)
High K^+, low Na^+	*Saltol*	1	Os01g20160, Os01g25280	Walia et al. (2005)
Salt-induced gene	*SalT*			
K^+/Na^+ ratio	*Saltol*	1	RM3412–CP6224	Tumimbang et al. (2005)
K^+/Na^+ ratio	*Saltol*		RM8094–CP6224	
Visual score	*qST1*	1	Est-2–RZ569A	Lee et al. (2006, 2007)
Na^+/K^+ uptake ratio	*qNAKUP-6*	6	RM3827–RM340	Sabouri and Sabouri (2008)
	qNAKUP-3	3	RM6832–RM7389	
Shoot Na^+, K^+ concentration	Expressed sequence tags	1, 7	qSNC-7 and qSKC-1	Lin et al. (2004)
K^+/Na^+ homoeostasis	Simple sequence repeats	1	QNa, QNa:K, SKC1/OsHKT8	Ren et al. (2005)
Improved Na^+, K^+ and discrimination of Na^+	Amplified fragment polymorphisms	1	QNa, QK1, QK2 and QNaK	Flowers et al. (2000)
Improves Na^+/K^+ ratio under saline conditions	*qNAK-6*	1	RM3827–RM340	Sabouri et al. (2009)
	qNAK-3	3	RM6832–RM7389	
Seedling salt tolerance	*qST-1*	1	Est12–RZ569A	Lee et al. (2007)
Improved Na^+/K^+ ratio	*qNAK-2* and *qNAK-6*	2, 6	RM318–RM262, RM176–RM345	Ming et al. (2005)
Control of shoot Na^+/K^+	*Saltol*	1	RM1287–RM10825	Thomson et al. (2010)
Na^+/K^+ ratio	–	1, 4, 6, 7	Single nucleotide polymorphism	Kumar et al. (2015)

Table 8.4 Improvement in salt tolerance of rice crops, using transgenic/genetic engineering approaches

Engineered gene	Source organism	Trait improvements	Growth improvements	References
Vacuolar Na^+/H^+ antiporter *AgNHX1*	*Atriplex gmelinii*	Activity of these antiporters was 8 times as great	Seedling survival increased by 51% or 81–100%	Ohta et al. (2002)
Vacuolar Na^+/H^+ antiporter *PgNHX1*	*Pennisetum glaucum* (L.) R.Br.	Well-developed root system	81% increase in shoot and root lengths	Verma et al. (2007)
Vacuolar Na^+/H^+ antiporter *OsNHX1*	Wild rice (*Oryza sativa* L.)	High accumulation of Na^+ and low K^+	Tolerance of salinity level of up to 0.2 M, whereas wild-type plants died	Fukuda et al. (2004)
Δ1-pyrroline-5-carboxylate synthetase (*P5CS*)	Moth bean (*Vigna aconitifolia*)	Greater proline accumulation under both saline and non-saline conditions	Shoot fresh weight increased by 30–93% and root fresh weight by 37–74% with exposure to 200 mM NaCl	Su and Wu (2004)
Na^+/H^+ antiporter *SOD2*	Yeast	Greater K^+, Ca^{2+}, and Mg^{2+}, accumulation and less Na^+ accumulation in shoots	Good performance under saline conditions	Zhao et al. (2006)
OPBP1	Tobacco	Good resistance against salt and disease	–	Chen and Guo (2008)

enzyme glutamine synthetase, which is associated with the chloroplast glutamine synthetase gene. In a study by Hoshida et al. (2000), over-accumulation of the chloroplast glutamine synthetase gene was incorporated into rice for better performance under saline conditions. Oxidized fragments of monosaccharides, such as mtlD and gutD fragments from mannitol and sorbitol, were used by Wang et al. (2000) in a transgenic approach for development of transgenic crops with salinity resistance.

Chen and Guo (2008) worked out a way to achieve high salt tolerance via a genetic engineering approach incorporating the tobacco gene *OPBP1* into rice and found that transgenic plants had high resistance to salt and disease under adverse soil and environmental conditions.

6 Future Prospects and Challenges

Salt stress is a major threat that influences cereal crop production. During the last few decades, various strategies have been devised to help overcome this threat through generation of salt-tolerant cultivars. Tremendous success has been achieved in terms of development of salt-tolerant cultivars of many crops, but progress with respect to cereal crops has not been quite so successful. Only a few such reports of salt tolerance are available for rice, wheat and maize, using conventional breeding, marker-assisted breeding and genetic engineering; so far, there have been no reports of such success in studies of barley, sorghum, pearl millet and oats.

Scientists have tried to develop salt-tolerant lines/cultivars of cereal crops through marker-assisted breeding and other approaches, but variations in environmental conditions, soil texture and salinity levels are major barriers that limit development of cultivars for salinity tolerance. The complexity of different developmental phases and the complex nature of salt tolerance traits, involving many different genes, are other major challenges in development of salt-tolerant cultivars. However, identification and pyramiding of several major and minor traits into cultivars to achieve durable resistance associated with different developmental phases and various levels of salinity could help to improve salinity tolerance beyond the seedling to reproductive stages.

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Chapter 9
Geoinformation for Land Suitability Modelling for Climate-Smart Farming in Africa

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Abstract Understanding what land areas are suitable for various crops has become very critical in this time and age. Abrupt changes in weather and difficulties in monitoring them have exacerbated the situation further, demonstrating the need for better technology to enable understanding of the available land and crop needs. A major component, therefore, of sustainable crop management is understanding of the limitations of a particular ecosystem. Spatial matching of agroecological ranges can provide baseline information that can be used for assessment of land suitability at different sites. Agriculture is directly connected to changing weather events and, over the years, has become extremely vulnerable to their adverse effects. Decision-making for various farming activities and/or crops to grow has also become a challenge. Various studies have highlighted the importance of using a geographic information system (GIS) in modelling of land suitability for better-informed decisions on choices of land for various crops. Land suitability modelling using GIS has become a very crucial step in improving understanding while, at the same time, detecting the factors that may limit the crop growth performance of any land. Various GIS models have been applied across different areas and have greatly helped to ensure informed decision-making for sustainable farming. GIS models have shown that land can be distributed into agriculture potential zones based on terrain characteristics, soil properties and climate properties. In this chapter, we evaluate what role GIS models play in development of land areas suitable for climate-smart farming.

Keywords GIS models · Land suitability modelling · Crop suitability · Soil suitability

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_9

1 Introduction

Agriculture relies heavily on climate. Over the years, crop production has suffered low yields as a result of vulnerability to adverse weather effects (Gregory et al. 2005). Climate change has been found to have negative impacts on agriculture; in particular, varying temperature regimes and changes in rainfall amounts have affected crop and livestock productivity tremendously. In Kenya, some areas have experienced increased rainfall amounts while others have experienced decreasing quantities. Temperature regimes have also been changing; in most areas, temperature increases have been experienced (Ministry of Environment and Forestry, Government of Kenya 2022). Because they are dependent on land resources, developing countries such as Kenya have experienced more adverse effects than developed countries have, and poverty severely limits the capacity of developing countries to adapt to these changes (Kabubo-Mariara and Kabara 2015). Limited technological know-how and limited ability to adapt to such changes have made the situation worse for some of these countries (Mwendwa and Giliba 2012). Finally, environmental stresses have made it more difficult to develop frameworks for resilience and adaptation strategies among small-scale farmers in Africa.

The world has been experiencing human population growth, which has caused mounting pressure on food production. A lot of progress has been made towards increasing food production in developing countries, but food insecurity has remained unacceptably high (Premanandh 2011). In addition, more than one in seven people still do not have access to sufficient food nutrition and suffer some form of malnutrition (Godfray and Charles 2010). Viable solutions have been sought, such as sustainable intensification (Godfray and Charles 2010), boosted production coupled with improved food distribution (Gregory et al. 2005), investment in agroforestry and hydroponics (Premanandh 2011) and agricultural research (AGRA 2014; CGIAR Research Program on Change, Climate, and Food Security 2014), among others. However, most of what is suggested targets one sector: food production under agriculture. Agricultural production remains a critical contributor to food security the world over (Sundstrom et al. 2015). The Food and Agriculture Organization of the United Nations (FAO) (2008) has noted that agriculture plays two key roles in attaining food security: producing food for people and providing employment for more than a third of the world's total workforce. In most parts of Africa, two-thirds of the population depend on smallholder agriculture (FAO 2008). In many cases, farming and livestock rearing are the main sources of sustenance for rural people in Africa.

Additionally, there has been little or no knowledge available about the anticipated changes and what mitigation strategies can be adopted. Agriculture remains the chief support system of Kenya's economy, directly and indirectly providing incomes for 75% of Kenya's population (FEWS NET 2013). Over-reliance on land resources increases vulnerability to climate change. Critical areas in agriculture must be assessed to continue generating food sustainably for the ever-growing population. With the needs to continue growing food and develop adaptation strategies in ever-changing climatic conditions, land assessment has become imperative (Taghizadeh-Mehrjardi et al. 2020). Assessment of land suitability therefore enables increased yields, since it means that crops can be grown in locations where they will perform best. Changes in weather patterns have altered most crop-growing zones the world over. Thus, land suitability assessment has become a vital tool to help enable any country to produce food without experiencing unprecedented losses.

2 Land Suitability Mapping

Land suitability is understood to be the ability of an area to support a defined use. The land may be considered in its present condition or after proposed improvements. Land suitability assessment may include a process enabling characterization of classes or groupings in particular areas that describe certain uses (FAO 1983). Analysis of land suitability has been described by the FAO (1983) as classification that enables recognition of qualitative aspects, quantitative aspects, current suitability and potential suitability. This formation of classes or groupings of certain areas by the FAO has been advocated for use in defining areas where crops can be planted on the basis of their characteristics. Thus, regions where land has been assessed for its suitability for animal husbandry, forestry or crop cultivation can undergo a different classification or grouping to enable identification of different areas where the said use is accommodated for a particular use in a more suitable manner. Assessment of how suitable the land is can be done both quantitatively and quantitatively (Taghizadeh-Mehrjardi et al. 2020). Qualitative analysis involves evaluation of information about hydrology, topography, vegetation, climate and soil properties. Under quantitative analysis, the evaluation becomes very detailed and yield estimation is done. This is translated into maps showing how suitable the land is for the proposed use, and it can provide planners within any given country with information that can help to boost food production while reducing land degradation.

In other regions, suitability is defined on the basis of various utilization aspects of agriculture. Irrigated agriculture is analysed with consideration of the potential of the area to provide enough water for production. Under these conditions, then, suitability needs are assessed on the basis of water requirements. As Alabyad-Mafraq et al. (2019) noted, semi-arid environments are now fragile and severely degraded by mismanagement of the available natural resources, and these problems are exacerbated by variability in weather patterns. In their study, analysis of land suitability was done using a geographic information system (GIS). Various areas with physical limitations were identified and defined to provide different alternatives for land use. Their study followed the guidelines and approaches highlighted by the FAO (1983) to define various classes that could be used to define the suitability of land in semi-arid areas of Jordan. The use of soil and climate was very instrumental in the application of the GIS system in that study. The general approach that was used involved checking and analysis of the characteristics or qualities of the land in relation to the different edaphic requirements of different types of use. In this case, GIS was utilized to match the different suitabilities to the utilization types available.

According to Alabyad-Mafraq et al. (2019), suitability analysis enables identification of factors that hinder agricultural production. In their study, they identified that different land use options could be applied to different land components. The conclusion of their study was that use of GIS to analyse the suitability of areas of land could enable identification of many land use alternatives that might otherwise have been ignored in the long run. In another study done in Kenya, Kuria et al. (2011) carried out a suitability analysis of land in potential rice-growing areas of the Tana Delta. That particular study used GIS to identify areas of land suitable for rice cultivation and applied the FAO's land suitability guidelines (FAO 1983) to establish different areas of the Tana Delta where rice could be grown. The study developed a model using ArcGIS software for the analysis and suggested various options for growing rice in the Tana Delta.

In analysis of land suitability in different areas, different classes and criteria have been applied so that generation of various suitability layers could be done, with overlays to show land use capabilities factoring in the various crop requirements. Khongnawang and Williams (2015) used 16 criterion layers for assessment of land suitability in an analysis of biofuel crop cultivation. Their study used multi-criteria decision-making analysis (MCDA) and an analytical hierarchy process (AHP) to run the analysis. Suitable areas were identified by matching potentially suitable areas with current land uses. The study used a GIS-based process, which was found to allow consideration of various criteria in the analysis while providing near-real-time and effective results. The process was effective in resolving issues of uncertainty while avoiding overlapping between different crop areas. A challenge identified during that particular study was identification of break points in areas; this was resolved by using the natural breaks in ArcGIS software.

Elsheikh et al. (2013) identified and developed an agriculture evaluation tool for assessing land suitability, using GIS knowledge and multi-criteria for identifying and analysing the geo-environmental suitability of land for cultivation of major crops in the tropic and subtropics. This system enabled decision-making using spatial data. That study highlighted challenges in the FAO (1976) guidelines, using matching tables and transfer functions, and noted that these were prone to some level of marginal errors. The study publication described the Agriculture Land Suitability Evaluator (ALSE) system, a land use management tool relying on intelligent techniques that could generate new knowledge on land suitability. Its ability to identify various land use alternatives was profound.

In another study, the utility of satellite imagery for assessment of soil compaction and suitability was assessed using remote sensing and GIS (Abdullah 2011). That study examined the correlation between remote sensing and in situ data, identifying and analysing potential soil compaction using linear regression and polynomials. The conclusion was that crop producers can use such products for soil suitability mapping to identify land areas suitable for cultivation of particular crops. This particular way of analysing land suitability was found to boost crop production through simultaneous integration of remote sensing, GIS, the Global Positioning

System (GPS) and sensor technologies to ensure that environmental quality was maintained.

As McDowell et al. (2018) noted, investigation of land suitability is a key concept in informing decision-making among various stakeholders. They pointed out that evaluation of the suitability of areas of land is vital for boosting production amidst existing environmental constraints, and they defined this particular concept as productivity within environmental constraints. The concept discussed in their paper included three indicators for assessment of land–water systems that focused on productive potential, relative contribution and understanding of the containment load. Conclusively, this conceptualization broadened analysis of land suitability to include wider impacts on the environment.

3 Available GIS Models for Land Suitability Assessment

Quite a number of GIS-based models have been used for assessment of land suitability for agriculture. Most, if not all, of the models have relied heavily on the FAO guidelines for defining the suitability of particular land areas on the basis of a classification that generates land utilization types based on crop types for production. With improvements in technology, these models have been modified over the years. This chapter evaluates various GIS models used in analysis of land suitability for crop production, pointing out their advantages while also highlighting their challenges. The importance of these models and their improvements, where relevant, are highlighted.

A study by Wanyama and Koti (2017) integrated GIS, quantitative analysis and suitability modelling in analysing the effects of climate variability on maize production. That study highlighted the struggles that rural farmers undergo because of variations in weather systems, and it used GIS and MCDA to analyse the suitability of maize-producing areas in Kenya. The study further explored use of geographic technologies and their applications in adaptation to, and mitigation of, the vagaries of weather, while exploring more specifically crop suitability modelling.

Crop suitability analyses and research studies on the correlation between climate change and agricultural productivity have adopted different methodologies to achieve their objectives.

Wanyama et al. (2019) used an ArcGIS tool known as a weighted overlay to bring together the six factors that could enable identification of land areas suitable for maize farming. This method was preferred because the user had a choice of allocating either different or equal weights to the factors. Raster data use was considered preferable for this tool. The tool reclassified values in the data input rasters into a scale that was common, multiplied each cell value by the raster weight and finally added the resulting values of the cells to create the output raster. For this analysis, AHP weights were used. The study concluded that successful integration of a geographically weighted regression AHP was key to assessment of land suitability, factoring in variability in the weather that could impact crop productivity.

The information generated by this tool was highly recommended as a decision-making tool for governments, farmers and planners. However, the research was generally affected by unavailability of spatial data.

In Ethiopia, teff (*Eragrostis tef*) is a major food crop. Kahsay et al. (2018) assessed models for evaluation of the suitability of land for teff cultivation in the northern semi-arid parts of Ethiopia. An MCDA GIS analysis tool was used to identify suitable land areas. In that study, a GIS-based AHP model was found to be superior for evaluation of teff cultivation potential in areas with various soils and landscape features. In conclusion, the study identified that the limiting factors for teff cultivation were two soil properties—namely, the morphological and physical characteristics of the soil.

Polytechniou et al. (1990) described use of MCDA as a spatial decision-making tool to enable assessment of alternatives on the basis of types and locations for these alternatives. The study used MCDA as an overlay process that allowed a set of layers to be combined for development of a decision map.

Taghizadeh-Mehrjardi et al. (2020) used machine learning models to undertake assessment of the suitability and sustainability of land for agricultural production. Their assessment focused on rain-fed wheat and barley cultivation in Iran. That research demonstrated the significance of maps generated through analysis of land suitability to inform planners on appropriate land use, and it further pointed out their importance for decreasing land degradation and assessing sustainable land use. The study was able to address a gap in the mapping of land suitability and associated information in semi-arid areas of Iran. The machine learning models explored use of various variables and significant soil analysis to understand spatial and temporal variations in soil classes and other soil properties. The machine learning utilized neural networks, partial least squares regression and genetic programming, among other models, to provide data and information about areas suitable for growing barley and wheat in Iran.

Machine learning has attracted a lot of interest in use of remote sensing for problem solving. However, use of machine learning to explore defined classes in assessment of land suitability is yet to be explored (McBratney et al. 2003).

Harms et al. (2015) used machine learning models to examine land suitability for irrigated crop cultivation and concluded that digitally derived land suitability frameworks could fast-track evaluation of the potential for agriculture in remote areas. Highlighting how fast and effective the process was, Hoseini (2019) developed a fuzzy logic system for optimization of a parametric evaluation system for surface and trickle irrigation in Iran. This particular system applied factors that were significant in determining areas of land suitable for irrigation. In this particular research, it was found that this approach provided high accuracy in soil change assessment. This provided information that was required for analysing the land to identify areas where trickle agriculture could be done. Furthermore, it was concluded that a fuzzy logic system provided a suitable grading method for improving water use efficiency in semi-arid zones and thereby improving on the parametric evaluation method for determining the best irrigation method.

In an assessment of GIS models, Vázquez-Quintero et al. (2019) developed a GIS-based framework for zoning of land areas suitable for grassland conservation in Mexico. This tool was based on multi-criteria evaluation techniques with a weighted overlay. The study chose four scenarios—non-intensive agriculture, intensive agriculture, urban and rural—and found that identification of suitable and unsuitable areas for grassland conservation was possible. It was concluded that the tool provided information that could be used for planning mitigation against grassland degradation. The maps provided by the tool became a good guide for detecting land where grassland conservation could be effected.

A model for land evaluation using GIS was developed by Abd El-Kawy (2010) to assist assessment for the best agricultural land use in the western parts of the Nile Delta in Egypt. This particular tool, ALESarid-GIS, targeted semi-arid areas of Egypt. The tool was based on MCDA using GIS, with a focus on assessing the suitability of land areas where it was possible to predict wheat and maize yield capabilities. The study concluded that GIS was a powerful tool for data handling, processing and management and for use in solving significant environmental problems. Significantly, however, there were problems in using the tool for yield prediction for some of the soil profiles, since the values fell outside the range of parameters in the polynomial equation within the model. In particular, the yield predictions were affected by soil alkalinity for wheat and the clay percentage for maize.

A GIS-based assessment of the suitability of land areas for alfalfa cultivation was done in the northern part of China by Deng et al. (2014), using 12 ecological and four socio-economic criteria. An AHP for determination of weights and MCDA were used for aggregation of the selected criteria. This approach relied on use of the FAO guidelines while applying spatial data on the areas. The tool that was developed was able to depict the spatial distribution of areas suitable for growing alfalfa in China.

Use of GIS for land suitability assessment has showcased the ability to boost production, enhance water use efficiency and reduce environmental degradation. However, these kinds of innovations and technologies are still limited in Africa and even more so in Kenya. Limited spatial data availability in most countries in Africa has a posed a challenge for various GIS-based analyses of land suitability and development of appropriate models.

4 Climate-Smart Farming

As noted by the International Fund for Agricultural Development (IFAD), there is now a consensus that climate change is having impacts on rural development. The changing dynamics of the physical and socio-economic landscapes are making smallholder farming more expensive. IFAD has suggested that smart farming should focus on vulnerability assessment through climate scenario modelling that enables understanding of the linkages between smallholder farming and the wider landscape. Secondly, IFAD has suggested that understanding of risk interconnections should enable scaling-up of multiple-benefit approaches that allow agricultural intensification on smallholder farms. This can build on climate resilience by managing competing land use systems at the landscape level. Thirdly, climate financing is a new way in which farmers can become beneficiaries, thus reducing the risks involved in offsetting transition costs and the risks of changing agricultural practices.

Geoinformation plays an important role in agricultural study, monitoring and remediation, which can be used for a great variety of applications. This book chapter discusses the ability of GIS-based models developed for land suitability analysis and how they can inform smart farming in the event of variability in weather. Furthermore, to boost crop production, simultaneous use of integrated geoinformation technologies in analysis of land suitability and maintenance of environmental quality are of paramount importance for attainment of food security.

Remote sensing, on the other hand, provides technology that is greatly needed as a diagnostic tool to serve as an early warning system to allow smallholder farmers to counter problems before they have negative impacts on crop production (Khanal et al. 2020). However, wider use of this technology across Africa is hindered by inability to access the available technologies. This is a result of lack of technological know-how, inaccessibility of data and lack of appropriate infrastructure. Remote sensing technologies have been available for the last 20 years to support site-specific management of decisions at various stages of crop production (Khanal et al. 2018). This technology not only increases crop production but also enables landscape assessment to help sustain environmental quality and profitability.

The FAO (2009) has estimated that by 2050, food production will need to increase by 70% to meet the growing global demand. Furthermore, the increased demand for biomass to enable a fossil-fuel-free economy further adds to the urgency to boost agricultural productivity. At the same time, major agricultural resources—such as productive agricultural land, water and nutrients—are limited at local levels. These challenges demonstrate the need to further model the suitability of land areas for cultivation of various crops to maximize the available resources. However, detailed information on where this can be carried out is lacking because of temporal and spatial variations in resources. In Kenya, for example, areas suitable for agricultural use are being converted for settlement while sensitive marginal areas are becoming new agricultural areas. These phenomena have actually decreased the amount of potentially suitable land for crop production in the country. Land use suitability planning, in this case, has become the key to addressing ever-increasing food needs by ensuring that good agriculture areas are safeguarded for crop production. Production improvements can best be realized if appropriate tools are applied to monitor large spatial and temporal variations—for example, in biophysical resources. The potential for greater use of GIS and remote sensing–based models is huge but largely unexplored in Africa. The models described here demonstrate the need to utilize available technologies to enhance smart farming in Africa. To work alongside these technologies, there is a need for up-to-date databases with available information that can be used. Such databases include soil, elevation, topography, climate and other data that are vital for land utilization mapping and analysis.

Governments in sub-Saharan Africa have shown interest in developing agricultural information systems, especially in countries where lack of reliable and timely information is a problem (Bégué et al. 2020). There has been a desire for improvement of existing systems and streamlined monitoring of agricultural information to better aid decision-making. However, the path from accurate and reliable information systems to public policy decision-making is not straightforward, and very few countries in Africa have been in a position to develop operational systems (Bégué et al. 2020). Development of early warning systems, pest and disease surveillance systems and sustainable agricultural land utilization systems requires huge investments in both data infrastructure and technological know-how. Furthermore, these information systems require use of geoinformation to build on reliable decision-making tools that can inform governments in Africa. Bridging of the gaps between geoinformation and agricultural policies in Africa is vital for producing operational recommendations. In a study performed in sub-Saharan Africa, Bégué et al. (2020) noted that there was a need to bridge the gap between technical analysts and policy makers. This can be achieved only through capacity building, political will, institutional commitment, public–private partnerships and proof of workable concepts.

5 Conclusion and Future Prospects

GIS-based analysis of land suitability helps to identify the main factors limiting agricultural productivity. This aids decision makers to come up with strategies that target better crop management for increased land productivity. Exploring land for various use alternatives is something that needs to be embedded in day-to-day planning by stakeholders. Periodical evaluation of land suitability not only creates resilience against climate change but also enhances sustainability of food production around the globe. Upscaling of technologies for analysis of land suitability is necessary if developing countries are to solve the many food security issues in play. The use of machine learning tools for land use class definition is another area that needs to be researched to enhance the availability of models that can enable food production through smart agriculture.

This book chapter has showcased the promising potential for assessment of land areas suitable for exploitation and many land use alternatives, taking into consideration sustainability of production and farmers' existing practices. Land suitability evaluations can be done for various purposes such as agriculture or settlement, or to evaluate the optimal land use in a particular region. Assessment of the suitability of land for cultivation of specific crops is becoming important as more crops continue to experience depressed yields in their current ecological conditions. Changes in rainfall patterns and ever-increasing temperature variations are parts of the new ecological conditions that have led to poor performance of crops under smallholder production. Various GIS-based tools and approaches have been found to work well in identifying suitable and unsuitable areas for cultivation of various crops. Each method has its advantages and disadvantages but, overall, the great challenge is the limited availability of data with sufficient temporal and spatial resolution to enable land use analysis.

The dependency of smallholder farmers in Africa on rain-fed agriculture poses great danger to agricultural production and productivity. Land suitability analysis, as described here, has shown that it can play a major role in sustainable use of scarce resources. In addition, land suitability analysis can be used extensively to help overcome the ever-growing problem of water scarcity in crop production. This should help to minimize overexploitation of natural resources and allow sustainable agricultural production.

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Chapter 10
Climate Change Adaptation: Remote Sensing-Based Flood Crop Loss Assessment to Support Crop Insurance

Rizatus Shofiyati, Sahat M. Pasaribu, Mohammad Ardha, and Yanuar R. Irawan

Abstract Farmers are always confronting with farm risks. Rice crop insurance program was introduced to protect farmers from the loss due to natural disasters and pest and/or disease. Flood causes farm damage or, in severe situation, a total harvest failure. This research aimed to investigate detection and identification of flooded areas using satellite images and to provide a scheme allowing parties in agricultural insurance to rapidly determine farm damage. Flood identification exploited C-band Sentinel 1 data with Ground Range Detected (GRD) mode, implemented in Java Island, Indonesia. In this research, Sentinel 1 data were acquired before and after flood events. The study revealed that Sentinel 1 could be used to map flooded areas with high accuracy of detection, in 2018 case. Acquisition gap, i.e., 12 days, however, needs to be supported with MODIS Terra satellite data to achieve sufficient level of data inputs for decision-making. MODIS Terra image analysis indicated that areas at which farmers proposed their claims generally experienced flood events between 3 and 7 days per year. Because of its quicker time in analysis with high accuracy outcome, it is strongly suggested that stakeholders would use remote sensing satellite data to detect and identify flood areas in supporting rice crop insurance policy.

Keywords Climate change adaptation · Ground range detected · Crop loss assessment · Flood · MODIS

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_10

1 Introduction

Global climate change clearly affects agricultural production. With such dire condition, farmers may suffer by increasing farm risks due to natural disasters and infestations. Agricultural activities, including during the food production, have been disrupted by such situations, and it appears that the evident tends to continue in the following decade. After the economic turbulence in 1998 led to a heavy monetary crisis, agricultural sector had shown its strong resilience by maintaining production, provide income in rural areas, and open job opportunities. Currently, after two decades, this sector for the second time faces difficult situation due to the negative impact of Covid-19 pandemic. Farmers should continue to work, maintain agricultural production, and adjust supply chain (distribution) to be accessible to all people. Therefore, food system, in this context, should ensure the farmers to work safely without any fear of losses due to harvesting failure while expecting good farm performance. The farmers should be protected from unexpected natural disaster and lead them to contribute to national food security.

Rice is a staple food for Indonesians. The government highly pays special consideration to ensure food availability and the distribution of goods throughout the country. Various policy instruments have been implemented to protect farmer's interests. With this concern, the Ministry of Agriculture has launched rice crop insurance program to secure farmers from farm risks caused by flood, drought, pest, and diseases. Agricultural insurance is one of the emerging approaches to stabilize agricultural sector and farmer's income, to support household economy, reducing debts, and in the long term, to improve agricultural production, which in turn, could contribute to a sustainable food security (Boyd et al. 2011).

Rice farm activity will always be accompanied by uncertainty and high risk of harvest failure due to natural disasters or high price fluctuation. Farmers may shift to other high value crops with less risk, and this is very dangerous in respect to national food security. If there is no action to counter this situation, negative impact on national food instability, specifically rice, will certainly threaten national safety. Agricultural insurance is very important to avoid great losses and ensure that the farmers are protected as shown by the availability of cash obtained from the approved insurance claim to be used as working capital for their respective farms.

To deal with the negative impacts caused primarily by floods, the Indonesian Ministry of Agriculture has launched rice crop insurance program in 2015, known as *Asuransi Usaha Tani Padi* (AUTP). AUTP scheme is expected to support farmers from undesirable farm experiences and their uncertainty during food production. With insurance claim, farmers may improve their chance to continue activities during the next planting season. Risks to be recovered under AUTP scheme include (a) flood (inundation in farmlands during the growth of rice plants over a period of time, causing crop damage, or even harvest failures); (b) drought (insufficient water during food production with partial or total loss); and (c) growth interfering pests and diseases. Claim is defined as a damage to rice plants caused by insured perils, with 75% loss or more. Site inspection is carried out by insured farmers and insurers, witnessed by local agriculture officers. Damage is determined, based on a claim report, prior submission (Pasaribu and Sudiyanto 2016). Upon completing claim assessment, the insurance company issues a letter of approval. Claim is subject to be paid within 14 working days upon the approval.

To this AUTP scheme, the remote sensing technology will be used to record the condition of the farm, from the early stage of production to the last phase of cultivation. The damage would also be detected with high accuracy and may not need human resource intervention, for example, physical visit to determine the farm condition. The possibility of using this remote sensing technology is expected to provide sufficient information in saving substantial costs in the implementation of agricultural insurance. Therefore, the use of remote sensing tools crop insurance would enable economic calculations that explain tangible and intangible benefits of such crop insurance scheme.

With respect to the claim, problems frequently occur during site inspection. Previous experience suggests that the performance of parties, especially during loss adjusting, could be amplified. The shortage of manpower capable in damage assessment causes late inspection leading to a detrimental effect to farmers. In order to minimize the impact, examining appropriate technology to improve and to accelerate the inspection of damaging farms is sought.

Remote sensing technology offers a suitable solution for the problem. With the ability to periodically record a large-scale region within a short period of time, this technology could contribute to the detection of flood areas. This would be useful in remote locations with poor accessibility. To date, wide range of sensors are available for the detection, in multispectral or microwave domains. With the frequent cloud cover during rainy seasons, limitations of multispectral data, especially in medium or high spatial resolution, are evident. An alternative to the confinement has been Synthetic Aperture Radar (SAR).

Variety of SAR applications has been introduced. This includes environment (Trisasongko et al. 2006), land cover (Panuju et al. 2019), and plantations (Trisasongko and Panuju 2015). Agricultural applications of remote sensing have long been developed to support agronomical aspect of food production, as well as its related issues. SAR data is even used to identify plant growth phases (Lestari et al. 2019). By intensifying climate change, water supply for agricultural land has also been investigated (Anderson et al. 2011). In addition, hazard-related issues are continuously studied to ensure food security at regional or national level. Galy and Sanders (2002) provides a broad application of SAR to inundation events, especially those that occur at the subsidence areas (Moe et al. 2017).

Recent SAR system in operation, however, might not meet big data required by insurance. Tackling with this problem, this research proposed a combination of Sentinel-1 SAR and MODIS Terra to exploit flood detectability and variability observation during inundation events. While both remotely sensed data were reportedly encouraging in agriculture (Gao et al. 2017; Setiyono et al. 2018), limited publications have been found related to supporting damage assessment in agricultural insurance.

The objective of this article is therefore to investigate the applicability of freely available satellite imageries to the identification of flooded agricultural fields, as an aid to parties involved in agricultural insurance. Specific discussion is firstly given in the statistical data, followed by the performance of remote sensing data as an aid to agricultural insurance.

2 Methodology

2.1 Study Location

Java Island, Indonesia (Fig. 10.1), was selected as research site. Situated in tropical region, the island has humid climate with high level of precipitation in wet season (from October to March). Dry season is characterized by lower rainfall; only some parts of the island experience completely no precipitation during April to September. Humidity and temperature is relatively stable and high throughout the year. These climatic conditions, along with fertile soils, create suitable environment to manage high intensity of agriculture, including paddy. Supported by vast irrigation systems, rice fields occupy about 3.5 million hectares (ca. 47% of country's wetland areas). Intensification has long been introduced in the Island, with the average of double planting seasons per year.

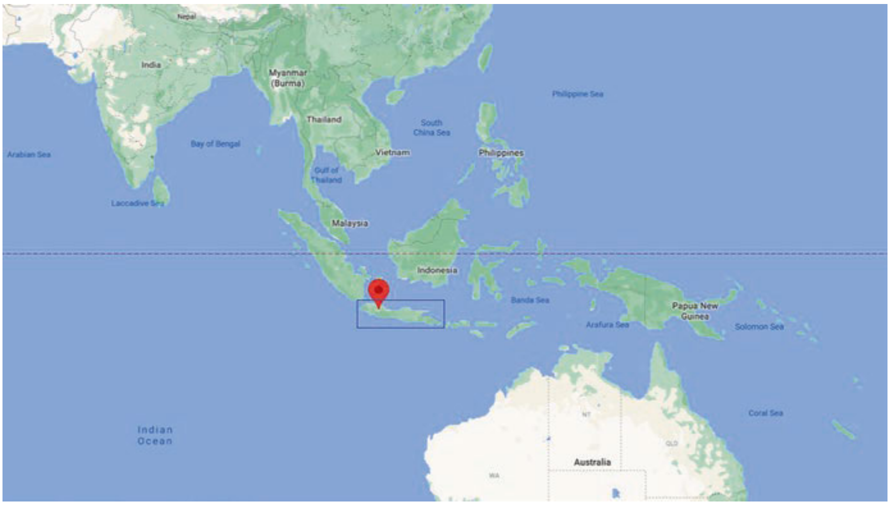

Fig. 10.1 Research location situated in Java, Indonesia

2.2 Datasets and Processing

This study evaluated C-band Sentinel-1 SAR data with GRD mode, freely available from European Space Agency (ESA). The sensor has two polarization states, i.e., vertical transmission and reception (VV) and vertical and horizontal cross polarization (VH). To be able to detect changes due to flooding, two acquisitions were evaluated in pre-assessment stage (Fig. 10.2). The first was pre-flooding dataset that provides baseline information prior inundation event. Impact of flooding was investigated using post-flooding data. The research exploited insurance claim data provided by PT Jasindo (insurance company dealing with the claims) and the Indonesian Ministry of Agriculture as the reference. The reference data consisted of location of the claims, which implied that inundation events can be directly extracted from the statistical data.

Sentinel data processing flow is presented in Fig. 10.3. The workflow exploited VV and VH backscattering coefficients derived from GRD format. The GRD data were firstly multi-looked to reduce speckle effects in SAR data (Small and Schubert 2008). Calibration was then performed to “convert” the digital number into backscatter coefficients, following (Febrianti et al. 2019). Terrain correction employing Range Doppler method was performed to fit the remote sensing images into the base map. To aid the processing, Shuttle Radar Topography Mission (SRTM) data were used to correct any distortion in SAR data. The threshold to isolate flooded areas was assessed from histogram of Sentinel-1 data. Samples for this binary classification (water and non-water) were done through image interpretation. The approach was developed from previous article (Liang and Liu 2020), suggesting that this research could yield overall accuracy of 98.9%.

After successful delineation of flooded regions, GIS clipping operation was performed based on cropland areas. In this research, those areas were extracted from Global Land Cover Copernicus. GIS analysis was done to ensure that flooded areas only occupied agricultural fields.

Temporal gap between Sentinel-1 SAR acquisitions might not meet detailed analysis over the area of investigation during the flooding period. With the absence of data, augmentation through data, feature or information fusion is often used. In

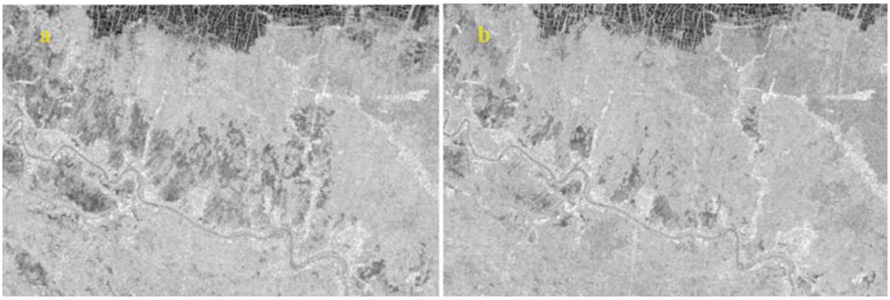

Fig. 10.2 Sentinel-1 datasets of before (left) and after inundation (right)

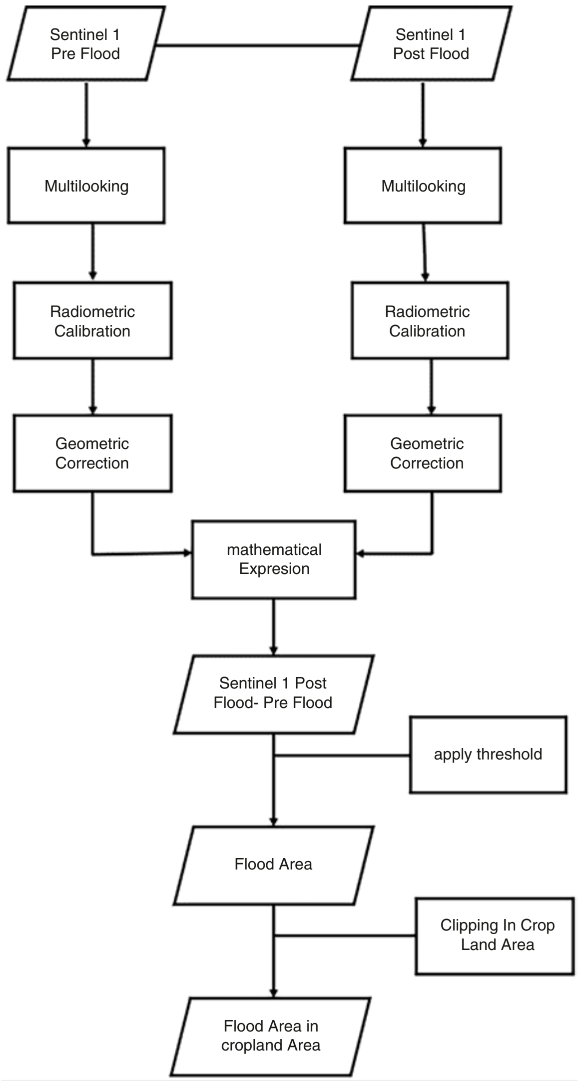

Fig. 10.3 Processing workflow for Sentinel-1 GRD data

this research, MODIS Terra data were exploited to further understand the dynamics of inundation over rice fields. The research employed 8-day data with spatial resolution of 250 m and seven spectral channels. All MODIS Terra surface reflection data were radiometrically corrected using Bow-Tie method. Additionally, all imageries were haze and aerosol corrected. Enhanced Vegetation Index (EVI) was derived from MODIS Terra data using the following equation:

$$EVI = G \frac{?_{NIR} ? ?_{\mathrm{Red}}}{?_{NIR} + \left(C_1\, ?_{\mathrm{Red}} ? C_2\, ?_{\mathrm{Blue}}\right) + L}$$

where ρ denotes atmospherically corrected surface reflectance, L is the canopy background adjustment that addresses non-linear, differential NIR and red radiation transfer through canopy, while C is coefficient of aerosol resistance term. In this research, adopted coefficients were, respectively, 1, 6, 7.5, and 2.5 for L, C_1, C_2, and G.

Further inclusion of rainfall data was beneficial for the analysis. This research employed Tropical Rainfall Measuring Mission (TRMM) datasets up to December 2019. As the mission ceased to supply the data, rainfall data from Himawari 8 satellite were used.

3 Results and Discussion

3.1 Flood Events and Their Impact on Agriculture

Rice crop insurance has formally been applied and gradually accepted by farmers since 2015. Since the implementation, insurance has assisted farmers in the rise of La Niña, when flooding events are likely to occur. Table 10.1 presents the occurrence of the phenomenon, indicating the frequency intensifies within the last two decades.

Based on statistical data obtained from the Directorate of Plant Protection, Indonesian Ministry of Agriculture, presented in Fig. 10.4, moderate category of La Niña sufficiently affected large scale of rice planting. As indicated, 2020 La Niña compromised over a 100,000 hectares. Prolonged inundation in 2020 accounted more than 20,000 hectares of rice fields. While the ratio of both figures were small, the scale of destruction would deliver a substantial effect to national food security.

Table 10.1 Records on La Niña effect in Indonesia

Weak	Moderate	Strong
1954–1955	1955–1956	1973–1974
1964–1965	1970–1971	1975–1976
1971–1972	1995–1996	1988–1989
1974–1975	2011–2012	1998–1999
1983–1984	2020–2021	1999–2000
1984–1985		2007–2008
2000–2001		2010–2011
2005–2006		
2008–2009		
2016–2017		
2017–2018		

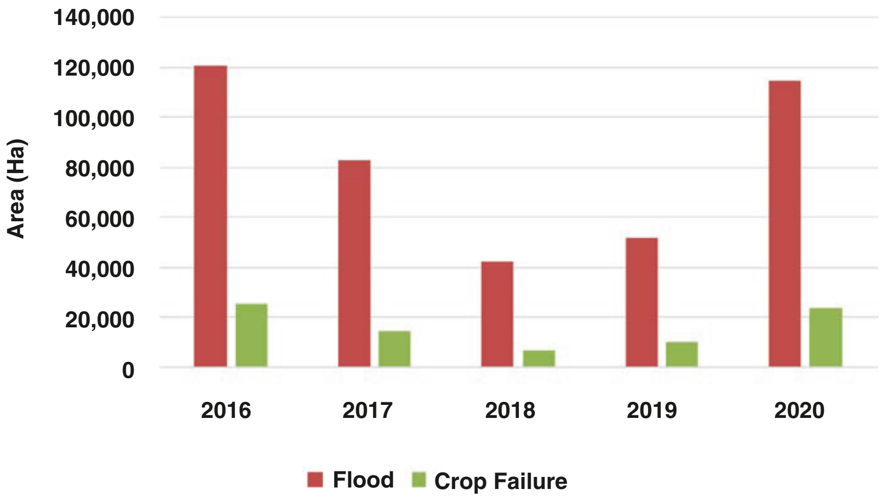

Fig. 10.4 Paddy fields affected by inundation (Shofiyati et al. 2021)

Table 10.2 Agricultural areas (in hectares), insured and claimed between 2018 and 2020

	2018	2019	2020[a]
Insured areas	614,185.88	691,270.63	496,075.15
Flood	1325.21	1787.96	775.45
Drought	2101.16	7603.22	148.47
Pest and disease	1313.08	2066.95	1686.30
Total claimed	4739.45	11.458.12	2610.22

Shofiyati et al. (2021)
Note: [a]Claim data up to 30 August 2020

3.2 Agricultural Insurance

Table 10.2 shows statistical data related to the insurance claims in Java Island, summarized by province. Generally, the statistics indicates fluctuated claims during 3 years of observation. The largest claim occurred in 2019 when major disasters happened in Java. Compared to other hazards, inundation has largely been minor to drought and pest/disease. Nonetheless, with respect to affected province, strong impact of flooding was observed in Central Java accounting more than 45% of the province claim. While a small relieve was shown in the province for 2019 case, its neighboring province, DI Yogyakarta, experienced large scale inundation. The province occupied total claim from flooded agricultural fields. In 2020, inundated rice fields in West Java covered more than 600 hectares, nearly similar amount with pests and diseases.

Statistics shown in Table 10.2 indicates that flood events require special attention with policy formulation to allow adaptation of all stakeholders to such situation. Interestingly, imbalance of claim logging existed which complicated the

Table 10.3 Claim intensity, 2018–2020

Year	Province	Claim Intensity				
			April–September		October–March	
		Total	Intensity	%	Intensity	%
2018	Banten	39	1	2,56	38	97,44
	West Java	50	4	8,00	46	92,00
	Central Java	67	2	2,99	65	97,01
	DI Yogyakarta	0	–	–	–	0,00
	East Java	77	2	2,60	75	97,40
		233	9	3,86[b]	224	96,14[b]
2019	Banten	6	–	–	6	100,00
	West Java	96	3	3,13	93	96,88
	Central Java	78	3	3,85	75	96,15
	DI Yogyakarta	2	–	–	2	100,00
	East Java	62	2	3,23	60	96,77
		6	–	–	6	100,00[b]
2020[a]	Banten	6	2	33,33	4	66,67
	West Java	53	5	9,43	48	90,57
	Central Java	37	16	43,24	21	56,76
	DI Yogyakarta	3	–	–	3	100,00
	East Java	17	13	76,47	4	23,53
		116	36	31,03[b]	80	68,97[b]

Jasindo (2020)
Note: [a]Claim data up to 30 August 2020, [b]Percentage of total claims

formulation. As shown in Table 10.3, insurance claim applications were skewed towards October to March period. The situation tends to be similar across provinces within 3 years of observation. The figure emphasizes the situation was fairly hectic to manpower allocation.

Based on technical guideline published by the authority, affected areas need to be examined, either by the insurer (normally represented by loss adjuster) or by local government officials representing farmers. This is to ensure that affected areas is properly determined and measured. Nonetheless, visiting large impacted areas may inflict difficulties for the insurer, since inspection requires substantial number of loss adjusters, when the disaster occurs in the same time covering wide areas. The situation may worsen in several regencies where rice fields are scattered throughout the region.

Technologies related with measuring the impact of hazards are beneficial to reduce the delay. In this sense, Earth observing satellite could be examined to estimate or to measure the influence of hazards over agricultural fields. Availability of different spatial resolution could distinctively contribute to various levels of investigation. Medium to coarse scale is advantageous for frequent monitoring to ensure examination of large scale hazards in daily or weekly basis. Meanwhile, detailed resolution data, including the ones from unmanned aerial vehicle (UAV), may be more appropriate for measuring the impact. But UAV has a lack in temporal resolution and must be operated by man.

3.3 Flood Analysis

Statistical data provided an excellent reference data for spatial analysis. Figure 10.5 depicts flood frequency distribution as the outcome of image analysis. By relating the map to Table 10.3, it is indicated that a relationship between both data could be established. Farmers claiming the insurance were situated in areas where inundation could occur between 3 and 7 times per year.

The figure indicates that lowland areas of Java Island, largely known as Pantai Utara Jawa (Northern Coastal Region, NCR), have been vulnerable to frequent inundation. The Northern Coastal Region is dominated by alluvial which extends from west to east and consists of clay, silt, and sand (Sarah et al. 2018), making the area more susceptible to inundation. The NCR has long been known as Indonesian primary bread basket, providing staple foods to other islands. In addition, it appears that important rice producers along major rivers such as Citarum in West Java, Serayu in Central Java, Bengawan Solo of Central and East Java, and Brantas in East Java have also been affected.

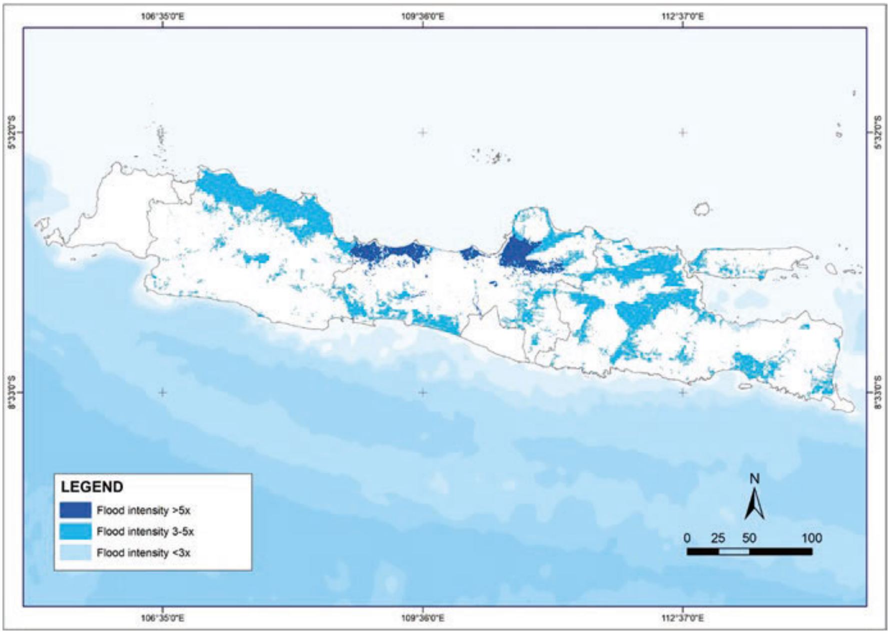

Fig. 10.5 Flood-prone map over rice fields

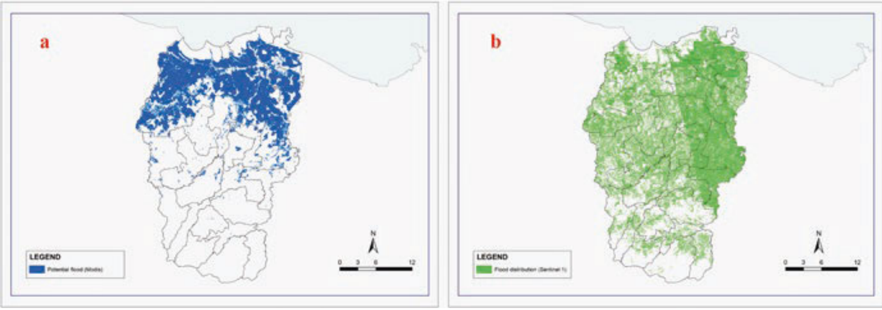

Fig. 10.6 Rice field map affected by flood in Java derived from Sentinel-1 (right) and MODIS Terra (left)

Figure 10.6 indicates data comparison between the analyzed flood area of two satellite data, namely, Sentinel-1 and MODIS Terra. Sentinel-1 data shows a more detail compared to that of analyzed by MODIS Terra. This is caused by its low spatial resolution with optical sensor influenced by thick cloud. Meanwhile, Sentinel-1 data with spatial resolution of 10 m with SAR sensor would be able to provide better information. However, MODIS Terra with its superiority in temporal frequency (daily) could be helpful to provide information when Sentinel-1 enable to record earth surface (12 days) even in (6 days) if it is combined between Sentinel 1A and Sentinel 1B. This is very important to note since the flood condition could change within 3 days.

The locations of affected flood were selected according to their administrative boundaries. Inspection was made to these locations where farmers have filed insurance claim. Since farmers in the areas of interest have not entirely participated in insurance program, accuracy assessment was made in some parts of the region. As shown in Table 10.4, estimation from remote sensing image analysis demonstrated its potential. Through combined information from combined passive and active remote sensors, the study achieved acceptable results. It was shown that the strategy coupled the advantage of high resolution Sentinel-1 data and high temporal information provided by MODIS Terra. This suggests that freely accessible remote sensing data could be beneficial for the practice of agricultural insurance. Although this information may not be fully fit into personal claim from individual farmer, the data would be more suitable for commercial or governmental purposes, or in a lesser extent, farmers' association.

Based on the table we can see from the claim if we crosscheck with remote sensing data, we can see accuracy in 2018–2019 has high accuracy more than 90%. But in 2020 it reduced and became 79%. Some of the related allegations include the claim area that is too small and spread out so that it cannot be detected by remote sensing imagery. Besides that, it could also occur because in 2020 there was quite extensive flooding in various areas on the island of Java, which resulted in a long time inundation flooded area so that with Sentinel 1 data, inundation could not be detected with data before and after the flood.

Table 10.4 Accuracy assessment image analysis results based on field data, 2018–2020

Description	2018	2019	2020
Total claim	146	64	407
Match with image analysis	146	60	324
Percentage (%)	100.00%	93.75%	79.61%

4 Conclusion and Policy Implications

Farmers always face difficult situations when exposed to risks in farm management. In order to ease the burden, governments, including Indonesians, have launched rice crop insurance scheme. Through registering as a participant, smallholding farmers would be able to receive initial capital to resume farming after experiencing risks, especially flooding, drought, and pests/diseases. Remote sensing technologies have been available to reduce burden in manpower management involving during field investigation. Sentinel-1 data can be used to identify and detect flooding in crop areas, thereby minimizing the need for stakeholders to directly investigate damaged areas. In addition, Earth observation data would help to identify remote areas that may not be accessible to field observers. Sentinel 1 has a lack of data to identify flood area which is small and scattered. While SAR data were found successful to distinguish flooded regions, the dynamics of inundation in Indonesia require a more frequent data observation. With the time gap between Sentinel-1 acquisitions being 12 days, supplementary data are required. In this research, MODIS Terra was found invaluable as a companion to Sentinel-1 data. Multitemporal EVI suggested that flooding frequency was about 3–7 days per year, which was beyond the temporal revisit of Sentinel-1.

Applied technology to support rice crop insurance is required to allow a more effective implementation. Short time of analysis, yet capable in producing high-quality information, needs to be developed. Considering their robustness, future insurance schemes should exploit remote sensing data with variety of spatial resolution to maximize their benefit for a thorough and rapid assessment of impacted rice fields. With a more readily available data, stakeholders involved in the insurance would be benefitted by a more reasonable manpower allocation. Cooperation among stakeholders, however, needs to be improved as human intervention remains the key for performing better insurance scheme.

Acknowledgments We would like to acknowledge institutions that supported through providing the dataset used in this article. They were Directorate of Plant Protection, Indonesian Ministry of Agriculture, Indonesian National Institute of Aeronautics and Space (LAPAN), and PT Asuransi Jasa Indonesia (Jasindo). Their eagerness to contribute to the analysis was highly appreciated.

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Part IV
Livestock Production: Technology Development, Transfer and Opportunities

Chapter 11
Smallholder Pig Value Chains Development and Livelihood Security

S. K. Mondal, K. S. Das, and S. S. Singh

Abstract World food situation indicating more incidences of mal- and/or undernutrition in developing countries points towards a future thrust on the low-cost animal protein production across the globe. The most cherished species may be the pig as it has some unique inherent characteristics as regards to growth rate, feed pattern, and fecundity. The scientific medium- and/or low-input pig management and pork production systems can have a tremendous potential for filling the current gap of demand and availability of animal protein in low-income countries. Managing pigs in a technologically improved way in terms of breeding, feeding, health care, and bio-safety and making the target group, i.e., small and marginal farmers well aware of these techniques, would capacitate them for ensuring their livelihood security at both individual and household levels. This would also enable them to take up future challenges in the face of globalization and financial hardship, if blended well with the policy-related essential modifications and institutional/organizational change. Thus, mobilizing pig resources can be a better weapon for fighting hunger and malnutrition in the future world.

Keywords World · Pig management · Livelihood · Health · Breeding

1 Introduction

The present world food situation, indicating 925 million undernourished people mostly concentrated in the developing countries (especially those in protracted crises), compels the world leaders, both at national and international levels, to exercise

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_11

the food security activities involving social rebuilding, livelihood provisioning, livelihood promotion, and livelihood security. Most vulnerable undernourished population of the world today are directly or indirectly involved in livestock farming activities due to their regional climatic harshness to conventional agriculture (Sansoucy 1995; Horowitz 2001). Again, the pig production in particular is a tradition in those communities, giving an extra point for cashing on this sector to imprint a social touch to the strategic development of these communities. In India too, the social development programs involving livestock component are an essential component of overall development, and recently, the Tribal Sub-Plan is directed towards the integrated approach of piggery development.

In this country, the indigenous pigs, during the 1940s and 1950s, were being kept under scavenging system of rearing with almost "zero input" and without considering the economics of production (Anonymous 2002). This was traditional for some specific tribes or communities, and their occupation and livelihood involving this traditional system of pig rearing would blend well with their landless and migratory situation. However, the then need of the community would also become fulfilled by the said farming. Gradually, Indian population exploded, so also their need or demand, leading to exploitation of more and more resources available at hand. The traditional non-descript indigenous pigs were no longer in a position to meet up the ever-increasing demand of the traditional tribals, leading thereby to improvement in existing genetic stock, their habitation, their production, and their cost-effective management. Thus the scientific management of pigs evolved. The import of improved exotic breeds, e.g., Large White Yorkshire, Middle White Yorkshire, Berkshire, Landrace, Duroc, Hampshire, Tamworth, Wessex, Saddleback, etc., for crossbreeding as well as adaptability studies during the late 1960s and early 1970s opened the avenue for taking up research projects on pig production leading to development of technologies for scientific pig breeding, feeding, housing, and control and treatment of swine diseases (Bhat et al. 2010). Then the gradual shifting from the traditional pig farming to scientific hygienic and economic pig production was started. During the last 40 years, the technologies are being developed by various institutions and transferred to the pig farmers for uplifting their living standard as well as socio-economic condition. Very recently, a trend is evident that people across all the social strata are coming forward with their schemes for scientific pig farming, thanks to societal changes due to increased literacy and increased demand for animal protein in the diet.

Pigs are distributed worldwide, and they possess wide adaptability to various climatic conditions ranging from extreme temperate climate of the United States to extreme tropical conditions of the African continent (CAST 2001). The world population of pigs is more than 941.2 million contributing to the most efficient pork industries in the industrialized nations of the world. In third-world countries, the importance of pig production sector and pork export is gradually increasing. In India, pig rearing is traditionally very popular among the tribal, backward, and economically weaker section of the society. Over last four decades, the zero or marginal input situation of this traditional pig farming is gradually changing with a paradigm shift of the society finding the swine production enterprise more profitable and remunerative.

1.1 Future of Pig Farming

Pig rearing is a tradition among the tribal, backward, and economically weaker section of the society in India and other developing countries. Over the last three decades, the zero or marginal input situation of this traditional pig farming is gradually changing with a paradigm shift of the society finding the swine production enterprise more profitable and remunerative. The present-day swine production is a profitable enterprise in all parts of the world, including India. The initial sporadic imports of improved exotic breeds by the Christian missionaries and subsequent piggery development programs taken up by the Government were mainly involved with the swine breeding for either the genetic improvement of the indigenous pigs or performance evaluation of the imported breeds. Since 1945, the gradual increase at the annual rate of 4.6% in pig population in India has indicated a steady growth of the swine production enterprise. The availability of domestic as well as export market for pork makes it more and more attractive. Moreover, the thrust by FAO for research on less-known species and relatively less remunerative agriculture because of gradual shrinking in average land holding due to societal changes and socio-cultural shift towards increasing acceptance of swine production by wider spectrum of the Indian population have a holistic impact on today's more comprehensive, modern, and scientific pig farming.

The Indian Council of Medical Research (ICMR) has recommended for 34 g/d meat consumption, but the availability of meat was 16 g/d in 2000 with the meat production of 4.25 million tons. This demand-supply gap for meat in general and pork, in particular, is gradually widening in these days of escalating protein hunger. Therefore, it is high time to streamline the breeding policy, to identify suitable breeds (preferably two or three), and to understand systematic improvement of indigenous pigs. This improvement in the genetic material of indigenous pigs through systematic breeding and subsequent selection is important for a giant stride in improving this sector.

One of the best meat-producing animals in the world is the pig that has high prolificacy with short generation interval, better mothering ability, faster growth, most economic feed conversion efficiency, and high dressing percentage. An integrated approach for livestock farming is the key to address various challenges faced by developing countries in achieving the food and nutritional security for growing human population (Ke 1998). Among all livestock species, the pig is the most potential source of meat and very efficient feed converters next to broiler. Apart from meat, pigs also produce bristles and manure. Pig farming registers quick returns because of its early attaining marketable weight within 180–240 days. There is a good demand of pig products, viz., ham, pork, bacon, sausage, lard, etc., at domestic as well as export market. Pig rearing creates employment opportunities for rural poor farmers, and it uplifts the living standard through supplementary income. Recently, a dramatic shift towards small- to medium-sized commercial pig farming with growing interest in self-employing educated rural Indian youth is being evident.

With the gradual change of societal and religious taboos, scientific pig rearing is gaining popularity day by day across the globe, and pig husbandry is being considered as one of the remunerative livestock enterprises. Pigs, as a potential meat-producing livestock species, possess the following advantages for a successful farming in the future:

- The pig has the highest feed conversion efficiency, which means they can gain maximum live weight consuming a given amount of feed than other meat-producing animals, except the broilers.
- The pig has ability to utilize the wide range of feed stuffs like forages, grains, garbage, and the poor-quality feed and can convert the same into high value meat. But, feeding of damaged grains, imbalanced rations, and garbage may cause low feed conversion efficiency.
- The pig is prolific and has shorter generation interval. A sow may be bred at around 240–270 days of age and may farrow twice per annum. It produces 6–12 piglets per farrowing.
- Farming of pig needs small investment particularly on the buildings as well as equipment.
- The pig is known for its higher dressing percentage (65–80%) comparative to other livestock species (less than 65%).
- Pork is a most nutritious meat which contains higher fat, lower water, and better energy value as compared to other meats. Pork is rich in many vitamins, e.g., niacin, thiamine, and riboflavin.
- Pig's manure/wastes are used in agricultural farming and fish pond as bio-fertilizer.
- An increasing demand of pig's fat has been found in soap manufacturing, poultry feed preparation, paint, and other chemical industries.
- Pig husbandry gives quick returns due to its early marketable weight.
- There is a good demand of different pig products.

2 Pigs as Resources

Pigs have become gradually important in the rural economy particularly in the north-eastern region of the country as well as in other parts. The pig provides food and nutrition to the huge number of marginal/small farmers and the landless rural people. This species has become particularly important for the socio-economic development programs running across the country for the tribal and down-trodden class of the society. Gradual shifting from traditional pig rearing to the scientifically managed pig farming on a commercial is happening today. World population of pigs is about 800 million. India possesses around 16 million pigs accounting for 2% of the world population. In India, pork production stands at 2.33 lakh tons, and the contribution of pork to the total meat produced in this country is around 8.2%. The value of pork products is 0.97% of total animal products, while it is 5.53% of total meat including meat products. Value of exported pig meat is Rs. 11.3 million (about 316.3 tons) against a total worth of Rs. 61,604 lakhs from the export of the meat including meat products. Value of swine bristles production is 30.42% of total hair production (Rs. 3780 million). The pigs and their products contribute Rs. 1797 crores annually to the national economy accounting for around 1.5% of the Gross Domestic Product (GDP) from livestock sector. But, in India, pigs are yet to gain their full production potential due mainly to wider adoption of most primitive form of pig rearing. Therefore, commercial pig farming under the intensive and semi-intensive systems of management following improved technologies will be crucial for realizing the potential of this unique meat-producing species. Relatively high demand for pork and pork products, especially in gradually increasing urbanized and semi-urbanized areas with potential of higher economic return, have been driving many businessmen, progressive farmers, professionals, the ex-servicemen, and the educated youth to take up pig production enterprise on a commercial scale.

In this context, more and more region-specific and farming system-specific technology development is the need of the day. For newer technologies to be developed, a road map of the research is necessary, and again, to draw a full-proof road map for future research, there is a need for the step-by-step procedure of technology development (Steinfeld 1998) which is typically outlined with the help of the technologies generated since its beginning. Therefore, the present document is a chronological account of the research works on pig production done at IVRI which is expected to cater the needs of the scientists, researchers, policy makers, and planners to assist them in outlining the future research strategies for further improvement in the socio-economic conditions of the weaker and down-trodden sections of the society in particular and the whole society in general.

3 Present Scenario of Pig and Pig Products

3.1 Pigs in Global Economy

World beef, chicken, and pork production totalled 275.2 million tons, in 2011, said UN's Food and Agriculture Organization (FAO), being 40% pork, 36% poultry (mostly chicken and turkey), and 24% beef. It represents a rise of 25%, or an additional 55.1 million tons of meat, compared to 2001. Of this increment, 30.6 million tons, or 56% of the total, was of chicken meat; 19.1 million MT, 35% of the total, of pork; and 5.4 million, 10% of the total, of beef (CAST 2001).

In the stream of the production increase, the share of each meat in the world production changes, with beef going down to 24% from previous 27%; pork, shrinking from 41% to 40%; and chicken meat rising from 32% to 36%. It is worth noting that while in 2001 the chicken meat production was equivalent to 76.5% of the pork production, in 2011 it was equivalent to about 90%.

3.2 Contribution of Pigs to Indian Economy

The average production from pigs in India is comparatively very less than developed countries of the world. The main cause of this is the zero input farming and non-adoption of improved swine production technologies by the traditional pig keepers. This leads to non-significant contribution of this animal resource to national income. Nowadays, farming of pig is not restricted any more to the backward class people. During 2008–2009, the worth of Rs. 2498 crores was generated from pork production. Pigs contribute significantly to the Indian economy by providing sustenance to the rural poor across the country, especially the north-eastern hills region. As per literature, pig population of this country is 11.13 million (Livestock Census 2012) which comprises around 1.18% of total population of world. The production of pork in India was 2.36 lakh tons (2009–2010). In 2010, contribution of pork to total meat produced in India was 5.9%. Value of pork products was 0.9% of total products from livestock, while it is 5.5% of the total meat including meat products. Pigs have very little contribution in Indian exports. Around 504.9 tons pork were exported in 2008–2009. The export value from pork was Rs. 27.9 million against a total export value (Rs. 8455 million) from meat/meat products. The value of swine bristles production was 30.42% of total hair production, which was about Rs. 3780 million. The pigs and their products contribute around 1.5% of the Gross Domestic Product (GDP) from livestock sector annually which contributes around 29.64% of agricultural GDP of the country.

Growing urbanization, rising per capita income, unfolding globalization, etc. are actually boosting the demand for high-value commodity like meat. With the fast changes of socio-economic conditions, there is rapid shift of dietary habits towards non-vegetarian food items. Due to this reason, demand of pork and pork products in the domestic market has substantially increased during the last decade, and the price per kg pork has jumped into Rs. 100–120/- from Rs. 30–40/-.

4 Scientific Pig Farming

Scientific rearing of pigs is to be resorted to for gaining better livelihood of the target people across the world, i.e., the down-trodden, the economically backward, and the resource-poor sections of the society. A holistic knowledge in various aspects of swine management will be pre-requisite for the application of various management-related technologies for capacity development of the targeted population. Therefore, a detailed description of the scientific way of pig management has been given here.

4.1 Breeding Management

Pigs are the meat animals and are being reared for production of high-quality animal protein from so-called low-quality roughages and concentrates. The suitable animal must grow well in the given feed and habitat situation. For this, selection of proper breed for the specific locality is of utmost importance. The growth rate and mortality are the two major determining factors; a compromise between the two is needed for selecting good genetic stock (Mondal & Verma 2011). A crossbred population might be a better solution to this rather than exotic animals. The local non-descript pigs (having average litter size at birth of 3–6) are to be crossed with the exotic improved breed (having average litter size at birth of 12–14) suitable for the locality to produce the crossbred population of desired exotic inheritance level (having average litter size at birth of 8–10). However, the recommended level of exotic inheritance should be up to 75%; 62.5% crosses usually register a good growth and disease resistance.

4.2 Feeding Management

Feed is the single item in the gamut of whole pig farming, which costs about 60–70% of the total cost production. Feed is the most important component that influences the profit from a swine enterprise. Successful swine production needs careful planning and an efficient management of feeding. The feed should be selected based on the tendency of pig farming for being more specialized and intensified even in rural areas. Through proper breeding and selection, rapid growing strains of swine have been developed. Owners of the farms now plan to market their hogs at 5 months of age instead of 7–8 months that was a practice a few years ago. Apart from this, planning for large litters (piglets at a time) and for breeding to farrow twice a year forces the swine producers to adopt refined methods of scientific feeding programs (Prasad 2000). Some important points to remember while feeding the swine are as follows:

- Feed the animals with best feeds to meet up their nutrient requirements.
- Give adequate concentrates with quality protein in their daily ration.
- Provide adequate vitamins and minerals with special emphasis on B-vitamins.
- Provide adequate clean potable drinking water during all the seasons.
- Give adequate exercise to the animals, either through paddock or small good-quality green pastures.
- Feeding of colostrum within a short period from birth is a must for the newborn piglets.
- While feeding the piglets, high-quality and more fortified diets are to be included in the ration.
- Before weaning at 6 weeks of age, it is better to provide adequate creep mixture of good quality for increased growth rate.

- Sufficient quantity of swine grower ration must be provided.
- Proper feeding of pregnant sows as per their nutritional requirements is very essential to increase litter size and to decrease the chances of piglet anemia.
- Nutrient requirements of lactating sows depend upon her body weight, age, stage of lactation, litter size, litter weight, etc.
- Conventional feed ingredients like maize, groundnut cake, wheat bran, and deoiled soya bean cake can well be used for pig feeding along with proper fish meal, mineral, and vitamin supplementation.
- Locally available non-conventional feed resources (kitchen and hotel wastes, cold storage wastes, warehouse wastes, etc.) may be utilized in place of balanced ration to minimize the cost for sustainable pig farming.
- Category-wise feeding regimes must be practiced to meet out all the nutrient requirements. The following specifications may be adopted to feed different categories of pigs (Table 11.1 and 11.2).

Table 11.1 Nutrient requirements for growing and finishing pigs

Type	Weaning pigs	Growing pigs	Finishing pigs
Live weight (kg)	5–12	12–50	50–100
Daily gain (kg)	0.30	0.50	0.60
Protein and energy			
Crude protein (%)	22.00	18.00	14.00
DE (Mcal/kg)	3.50	3.50	3.30
ME (Mcal/kg)	3.36	3.36	3.17
Inorganic nutrients (%)			
Calcium	0.80	0.65	0.50
Phosphorus	0.60	0.50	0.40
Sodium	–	0.10	–
Chlorine	–	0.13	–

Table 11.2 Nutrient requirements for breeding and lactating pigs

Type	Breed gilts	Lactating gilts and sows	Young boars and adult boars
Live weight (kg.)	110–250	140–250	110–250
Protein and energy			
Crude protein (%)	14.00	15.00	14.00
DE (Mcal/kg)	3.30	3.30	3.30
ME (Mcal/kg)	3.17	3.17	3.17
Inorganic nutrients (%)			
Calcium	0.75	0.75	0.75
Phosphorus	0.50	0.50	0.50
Salt	0.50	0.50	0.50

4.3 Housing Management

Pig houses, otherwise known as sties, should provide protection against inclement weather and proper hygienic conditions for maintaining their healthy growth. In India, semi-indoor system of swine farming in loose houses is generally suitable. However, at places of extreme climatic conditions, some locally suited modifications of structural designs and construction materials may be sorted out under some expert opinion. Separate sties for different ages should be provided for proper management in respect of feeding, weighing, as well as hygiene (Sastry et al. 1983). As per BIS standards, various dimensions are as follows (Table 11.3).

Boar must be housed in individual stall grouped under one roof. Number of breeding boars to be kept in the farm would decide the number of stalls to be constructed. For gilts and dry sows, simple loose houses with cement-paved floor in covered area and brick-lined floor in open area should be provided separately on larger farms, however, together on smaller farms. These sties may be put in a row, and a relatively smaller group (3–10) of pigs should be housed. Each farrowing-cum-nursing sty should accommodate one sow with its litter. Advanced pregnant gilts or sows are transferred to these sties around a week before due date of farrowing and are left here during nursing period also. This should be roomy enough for sleeping space of sow as well as roaming space for piglets. Guard rails should be provided along the walls 25 cm above the ground level to avoid crushing of piglings. For housing fatteners, 15–30 pigs should be housed in each pen depending on their age. Piglets that are weaned should be housed in weaner piglet sty in a group of 30 up to 6 months of age.

The feeding and watering space required for various categories should be proper and as per standards as these have a direct influence on the production and reproduction performance of pigs. The BIS has recommended the provision of manger (feeding) and waterer (drinking) space as presented in Table 11.4.

Table 11.3 Standard space requirement for various categories of pigs

Type of animal	Floor space requirement (m^2)		Maximum number of animals per pen	Height of shed at eaves (cm)
	Covered area	Open paddock		
Boar	6.0–7.0	8.8–12	1	200–250
Farrowing sow	7.0–9.0	8.8–12	1	
Weaner/ fatteners	0.9–1.8	0.9–1.8	30	
Dry sow/gilt	1.8–2.7	1.4–1.8	3–10	

Table 11.4 Feeding and watering space requirements for different categories of pigs

Type of animal	Space per animal (cm)	Total manger length in a pen for 100 animals (cm)	Total water trough length in a pen for 100 animals (cm)	Width of manger and water trough (cm)	Depth of manger and water trough (cm)	Inner wall's height of manger and water trough (cm)
Growing pigs	25–35	2500–3500	250–350	30	15	20
Adult pigs	60–75	6000–7500	600–750	50	20	25

Table 11.5 Vaccination schedule against different pig diseases

Sr. No.	Name of disease	Type of vaccine	Time of vaccination	Duration of immunity period	Remarks
1	Foot and mouth disease	Polyvalent tissue culture	At about 6 months of age with booster done after 4 months	One season	After booster dose of vaccine, repeat every year during October/ November
2	Hog cholera	Lapinized	After weaning	1 year	
3	Swine pasteurellosis	Classical bovine	At about 6 months of age	1 year	

4.4 Health Management

Pigs are naturally susceptible to common swine diseases like swine fever and foot-and-mouth disease, besides occasional injury/wound, fever, and gastro-intestinal complications. Conventional treatment with analgesic, antipyretic, and hepatic boosters in appropriate dosage would yield desired results without much complication in general, but, on the other hand, some specific expertise in some surgical cases like tooth clipping in breeding males, castration for making teasers, etc. would also be required (Banerjee 1991). The medication in fatteners mainly involves the agents for vaccination and deworming apart from a few therapeutic agents used during their shorter farm life of about 6–8 months. Signs of illness should be noticed at least twice a day. These are fever, low feed intake, unusual/abnormal discharge, abnormal behavior, etc. The animals should be protected from commonly occurring diseases. During outbreak of contagious diseases, the sick and the healthy animals must be segregated immediately. Side by side, other disease control measures are to be adopted at the earliest. Deworming of the animals should be done regularly. Feces of adult pigs should regularly be examined to check the presence of eggs of internal parasites, and the infested animals should be treated with suitable drugs. The animals should be washed during hotter parts of summer days to reduce heat stress as well as to promote sanitation. Recommended vaccination schedule should be strictly followed for preventing some common pig diseases (Table 11.5).

4.5 Reproduction Management

The gilt becomes ready for breeding by the age of 6–8 months depending upon the breed and nutritional status. The sexual maturity in boarlings is noticed by the age when they are of 6–8 months. The breeding of males and females of similar size, conformation, and temperament is preferred. The heat period lasts up to 5 days in sows, which may be reduced considerably if earlier mating/service is done. The length of estrous cycle in pigs is 18–21 days. The usual male-female ratio in an ideal breeding stock is 1:10. It is desirable to detect the animals in heat twice a day, preferably morning and evening. The services should be given twice in a heat period. The gestation period lasts for about 114 days and should be accompanied by proper nutrients. The post-weaning heat is usually observed after 3–10 days of weaning. Before breeding of sows, special nutritional supplementation for increasing the number of ova and decreasing the chances of early embryonic mortality is needed.

4.6 Symptoms of Heat in Females

After attaining the age of sexual maturity (6–8 months depending upon the breed), the gilts experience the cyclic pattern of behavioral estrus (heat). The common signs of heat in females include swollen and reddened vulva, excitement, restlessness, mounting others or allowing mounting by others, twitching of tail, and "lordosis" or immobilization in presence of male/teaser. Typical interest in following the attendant is usually observed during the morning check. The best indicator is the immobilization response of estrous female. As a reaction to a combination of visual (sight), auditory (sound), olfactory (smell), and tactile (touch) stimuli originating from the boar, sows and gilts in estrus exhibit this immobilization response.

4.7 Signs of Approaching Farrowing

- Pregnant females become lethargy during the last week of gestation. Most of the time they spend in the closed area. Pregnant females are found lying down most of the time in the chamber.
- Feed intake goes down in the last week. On the day, pregnant females stop taking feed but consume water frequently.
- Volume of mammary glands increases abruptly. Milk secretion starts on the day of farrowing. Turgidity of teats is prominent.
- Just 10–12 h before farrowing, a peculiar behavior of nest building (the most significant behavior) with or without bedding materials is seen.
- Biting of bars or any other hard materials and occasional twitching of tail are the common behavioral signs.

- Restlessness, straining, increased respiration rate, frequent urination, and increased frequency in standing up and lying down are common behavioral activities during the onset of farrowing process.

5 General Management

5.1 Neonatal Care in Pigs

The newborn piglets are prone to thermal variations, and there is need to protect them from extreme cold weather conditions by providing the artificial heat sources like *bukhari*, brooder box, etc. After the completion of farrowing, the naval cord of the neonate is usually cut at a distance of 2.5–3 cm from the body, and tincture iodine solution is applied over it to ensure prevention of entry of any type of infection. The needle teeth (4 pairs) are removed along with the naval cord treatment to prevent the chance of injury to the udder and teat of the mother as well as in the snout and adjoining areas of the piglets.

Care and management of piglets is one of the most important activities in pig farming. Profitability of any farm is positively correlated to a number of healthy piglets born as well as weaned per sow in a year. Piglet management starts from the day it is born till their separation from the mother (weaning). The advanced pregnant sow is allowed to remain in the farrowing shed for the period from farrowing to weaning. The following items are required to be kept ready in the farrowing shed to ensure proper peri- and neo-natal care and management:

- Bedding materials, viz., straws, wood scraps, bhusa, saw dust, etc.
- Scissors or knife to cut naval cord of piglets.
- Tooth cutter if clipping of tooth is practiced.
- Antiseptic solution, viz., savlon, betadine to apply over naval after cutting.
- Cotton threads to tie naval chord of piglets.
- Wooden box with heat lamp as brooder to provide heat particularly in winter season (December to January).
- Cotton rolls.

5.2 Management of Pregnant and Lactating Females

A female pig remains in two physiological stages, viz., gestation and lactation, in most of the productive life cycle. The success of these two life processes determines the worthiness of a female and thereby profit for the farmer or producer. Therefore, females need scientific care and management during gestation and lactation.

5.3 Care of Sow During Gestation

Care of sow during pregnancy is care of piglets that are to take birth. Proper feeding with balanced diet during gestation increases birth weight of piglets and increases the chance of growing up to adult stage as mortality of healthy piglets is very less. Proper feeding and housing environment during lactation reduces mortality of piglets and augments the reproductive efficiency of sows. Healthy nursing sows come into heat about 7–10 days after removing piglets from female. Housing, breeding, and feeding are the three major basic aspects of sow rearing.

5.4 Care During Farrowing

A female seldom needs external help during farrowing. However, there should be strict vigilance as difficult farrowing needs manual help. Piglets are generally born either head first or rear feet first. Sometimes, piglet is covered by placental membrane. In such case, the membrane should immediately be removed to facilitate breathing; otherwise, leave the piglet by itself. Piglet stands on its own feet within 2–5 min of birth. Sometimes, piglets cannot stand due to slippery floor. Piglets can be manually pushed towards dry areas to enable it to stand. If naval cord does not detach from dam, that may also prevent piglets from standing. The cord should be manually severed by an aseptic knife. In severe condition, it is wise to consult a veterinarian. In very cold climate (December to January) when environmental temperature goes down to below 10 °C, it is very important to dry the piglets immediately after birth with a cloth. They can also be kept under heat lamp in brooder box.

A special farrowing pen is constructed for pregnant sow for farrowing. Construction layout is the same as described above. Farrowing pen should be dry and floor should be concrete and level. Normal desirable ambient temperature in the chamber is to be 22–28 °C. The minimum floor space requirement for a farrowing female is 7–9 sq. m. for covered area and 8–12 sq. m. for open paddock. Sows are kept individually in the farrowing chamber. Iron pipes (guardrails) are fitted in three sides in the closed area. The guard rails should be constructed 8–10 cm from the wall and at 8–10 cm height from the floor (Tiwari et al. 2009). Preferably, water trough should be constructed in the run. Overflow of water in the closed area sometimes make the floor slippery and unhygienic. The slippery floors make the movement of sow very difficult. Pregnant females are brought to this special chamber before 1 week of farrowing. Before shifting to farrowing chamber, the females should be sprayed with chemicals like botox or cypermethrin (1%) to get rid of lice and mite from the body. The walls and floor should be cleaned and scrubbed thoroughly before shifting of animals. Disinfectants like lime, bleaching powder (3% w/v), and washing soda (4% w/v) should be sprinkled.

At farrowing time, special attention should be given to the sow while allowing it to farrow by itself if the condition permits. Normally, the farrowing process completes in 1.5–3.0 h. Sows seldom require assistance while farrowing, unless the sow exhibits restlessness and excessive straining, and the interval of expulsion between two piglets is more than 15 min. Females giving birth for the first time, older, overweight, or nervous sows may have more farrowing problems. Large-sized piglets, effort of expulsion of two piglets simultaneously, and piglets entangled with umbilical cord sometimes lead to condition of asphyxia. In this condition, death of piglets due to hypoxia is very common. The placenta comes out within 1–6 h after the last piglet comes out. The placenta should be removed from the chamber as soon as it expels. Its consumption is detrimental to the health of the female.

5.5 Care of Sows During Lactation

Proper feeding and housing environment during lactation augment the reproductive efficiency of sows. Piglets can be weaned earlier if they grow faster; that may happen if nursing females are well fed. Healthy nursing sows come into heat earlier after lactation period, thereby increasing its efficiency of producing more litters per year. Piglets are solely dependent on dam's milk production during the first 20 days of life.

6 Capacity Development and Pig Production

Worldwide ownership of pigs largely constitutes the small and marginal farming population specifically in third-world countries. This pattern has necessitated the need of extensive support services to the targeted pig producers in terms of legislation, veterinary services, input supply, market access and transport, etc. apart from the extension services (Dietze 2011). In true sense, the capacity development in terms of knowledge as well as skill needs a typical farming system-specific blending of all the abovementioned components for promoting/mobilizing pigs as resources across the global economic spectrum. These drivers/factors of support systems for the required capacity development in pig farmers have been discussed below.

6.1 Extension Services

Investing in public extension service sector and encouragement to private services have become essential when pig farming has to exert positive impact under small-scale farming system. To improve overall pig husbandry practices which lead to enhance safe pork production as well as production of pork products, extension works in agriculture sector require support. The service rendered in this sector must assure knowledge transfer in good pig husbandry practices with local setup. Farmer Field School (FFS) has been developed in livestock as well as has provided effective transfer of the technical knowledge on matters related with production. FAO developed a method that is basically a concept of "learning-by-doing" approach in which small-scale farmers have got opportunity for learning directly through field experience.

Extension services are required to use a combination of production knowledge as well as skills especially in the training programs in marketing and such other business-related skills. Sustainable pig enterprise can be possible when there is an assured market for pork and other pig products. It can prosper if small farmers have knowledge about marketing, understanding of their local markets, and can sell the pig products. Small-scale farmers should also know about the method of calculating costs, estimating yields, as well as evaluating potential profit. Knowledge about practices related to business, e.g., farm record keeping, cash flow and gross margin, etc., are also very essential for successful pig enterprise. In addition, extension is required to contribute towards improving overall health of pigs, safety, and hygiene issues associated with pork products. Coupled with appropriate and in-depth training, the small-scale pig rearers can learn the knowhow associated with hygienic and safe practices through simply following "prevention is better than cure." The role of extension workers to support small-scale farmers in pig production enterprise covers the areas which range from making the opportunities as well as challenges in pig production sector and other related sectors like supply of feed, credit availability, medicine supply, marketing improvements, and encouragements to farmer associations.

6.2 Legislation

The majority of legislation found today particularly in developing countries like India lacks pro-poor initiatives which can support pig enterprise in small scale (Birthal & Taneja 2006). Participating in formal food supply chain, food safety regulations involving needs, necessities, and practicalities, role of health, production, and standards of food safety are among those important bottlenecks for small farmers when they want to access various types of more formalized marketing chains, and this forces the small-scale farmers to remain within informal and almost uncontrolled sector. The development of standards which consider small farmers along with institutionalized support systems results in enhanced livelihoods security. Such approaches have become successful in sectors like dairy in many countries in the globe.

Need for a legislation facilitating provision of a good business environment is there for its application at both national as well as local levels. Implemenation of such a legislation must encompass the general agricultural sector as a whole, and swine production sector in particular in rural areas. This will be possible only when the legislation related to land, private credit institutions, and trade and training services will be properly blended for the overall goal of promoting sustainable pig production in smaller scale. Such blending requires a full-proof plan involving all the stakeholders starting from input suppliers to retailers.

6.3 Veterinary Services

The veterinary services, typical for pig enterprises, are almost negligible apart from some public health hazards emerging in recent years. Otherwise, the livestock health services as a whole can be well-utilized for specific purpose of maintaining pig health. Overall, the para-vets, community health personnel associated with animals, and public sector animal health professionals can cater to the technological needs of the small-scale pig farmers. At the same time, there should be a binding legislation regarding pig health for the large-scale pig producers in the aspects related to vaccines, medicines, and services rendered by the public sector technical persons. Approach may be top-down, meaning the application should be effected at national, then regional, and then local level for efficient veterinary services.

Besides, slaughter and the surroundings of slaughter houses are to be optimally controlled by veterinary professionals in order to have a safe and hygienic production of pork and pork products.

6.4 Financial Services

Due to poor resources, the small pig farmers are not able to access the regular financial services, and this results into subsistence farming and not market-oriented farming. The situation may be tackled to some extent by extending certain kind of promotion and creation of congenial environment for credit institutions by assuring their credit profitability by strengthening the small pig farmers. The marketing options available with the small farmers are to be more open, and start-ups for the piggery enterprise may be with incorporation pregnant females and distribution of their offsprings as in dairy sector. More profitable market for small farmers and extended credit systems through planned schemes will surely boost the capacity of doing piggery business in small farmers.

6.5 Input Supply Chains

The most important input for the pig production is the feed and that too in a fair price. And if this is assured, then the enterprise will automatically flourish. The characteristic problem of small-scale producers is that the inputs like feed, improved equipment, medicines, etc. are not locally available, and thus they require a supply chain for these inputs. This chain will be successful once the ease of doing business will be in place for input suppliers. Concentrate feed at comparatively less prices and knowledge of mixing local ingredients can well help the small-scale pig producers along with sophisticated slaughtering technique.

6.6 Access to Markets

The availability of good-quality genetic materials is the biggest constraint in sustainable small-scale pig production. Market standards set by large pig producers are generally not met by the native breeds, and poor productivity of such breeds and such constraints are being faced by small pig farmers. Apart from the genetic materials, the inputs and products are also a part of established market chain. If the small farmers are to be an active part of it, there should be the formation of farmer-producer organizations (FPOs) as well as commodity associations.

Further, contract farming can be another option for small-scale producers, but their agreement and conditions should not be dominated by large players while their marketing interest must be protected. Awareness for consuming pork and pork products and development of infrastructure like transport can also help in promoting small pig production enterprises.

6.7 Transport

As the small-scale pig rearers are located at remote rural areas and the potential market for the pork is in the city areas, there should be fast and efficient transport system to maintain an effective production-consumption axis. The persons associated with such transport of perishable items may be made technologically upgraded to reduce loss. The vehicles, refrigerated transport system, will also help in increasing profit too.

6.8 Organizational Options and Gender

Building capacity in the farmers, input suppliers, and transport workers through suitable organizations and making them aware of the formal demand-supply chains can improve the status of the small producers. The formal public institutions can properly address the issue of capacity development. Again, the farmers' organizations, commodity associations, etc. can make the small pig farmers, processors, butchers, etc. able to respond to various market situations more boldly by increasing their risk-taking ability (Ashdown 1992).

Another dimension of rural small-scale pig production in most part of the world is gender issue. Being typically managed by women and children, pigs have an advantage over other livestock. This concern may be well addressed by forming some women farmers, organizations that may take care of the issues related to ownership, credit facility, and marketing by women.

7 Target Groups for Capacity Development

In developing countries like India, small and marginal farmers represent >86% of farm families having holding size of <1.2 ha live in diverse production condition with high risk. Fragmented land units don't allow the small farmers to have individual farm resources, e.g., tractors, draught animals, bore/tube wells, and such other sophisticated agricultural machineries for different operations. Till date, the focus was on maximization of yield/growth rate only and that too for rich farmers. To fulfill basic requirements of such households like food for humans, fuel, feed, fodder, and fiber, a focused attention to livelihood enhancement options through system approach is warranted.

Indiscriminate fragmenting of land units results from weakening of traditional concept of joint family along with unchecked growth of human population. Approximately >85% of total farm families were converted to small and marginal farmers with land <1 ha. Majority of inputs became costlier and out of reach of small farmers, and this results into less- or un-economic and less- or un-sustainable farming. Today's need of higher scale of urbanization and growth of industrial sector as well as infrastructural growth necessitated to look for growth vertically rather than horizontally so far as agriculture is concerned. The characteristics of small and marginal farmers are that they are in general illiterate, are financially handicapped, and have small holdings which are scattered and unsuitable for high-tech farm machinery. A lot of efforts aim at increasing per unit productivity of various components of production systems but lack in integration through following a holistic approach involving whole farming system.

Smallholders require support for taking advantage of opportunities given by a continuous expansion of pig production sector and for managing risks involved in increasing competition as well as closer linkages with present newer value chains. This needs significant as well as sustained innovation in food and agricultural production systems at all levels – global, national, and regional – and technological innovation, capacity building, mixture of policies, and institutional change and investment that are gender-sensitive and are responsive. There is an ample scope to improve technical knowledge among school dropouts, rural youth, and farm women about small-scale production through providing capacity development training programs at farmers' doorstep.

8 Livelihood Security and Pig Production

Livelihood of a person refers to their "means of securing the basic necessities-food, water, shelter and clothing- of life." Livelihood is defined as "a set of activities, involving securing water, food, fodder, medicine, shelter, clothing and the capacity to acquire above necessities working either individually or as a group by using endowments (both human and material) for meeting the requirements of the self and his/ her household on a sustainable basis with dignity." Usually, these activities are accomplished repeatedly. Livelihoods include range of off-farm and on-farm activities that provide various procurement strategies of food as well as cash. In this way, each household has several probable sources of earnings that constitute the household's livelihood (Beckwith 2000). Such entitlements are mainly based on subsidies which a household may have, and the household's position in social, legal, political fabric of the society (Drinkwater and McEwan 1992). Livelihoods are considered secure when household has "secure ownership of, or access to, both tangible and intangible resources and income earning activities including reserves and assets, to off-set risks, ease shocks, and meet contingencies" (Chambers 1989). Another view is that households have livelihood security while they have the ability to acquire, utilize, protect, develop, exchange, and benefit from the assets as well as resources (Ghanim 2000). As per Frankenberger (1996), household livelihood security (Fig. 11.1) has been defined as "adequate and sustainable access to income and resources to meet basic needs (including adequate access to food, potable water,

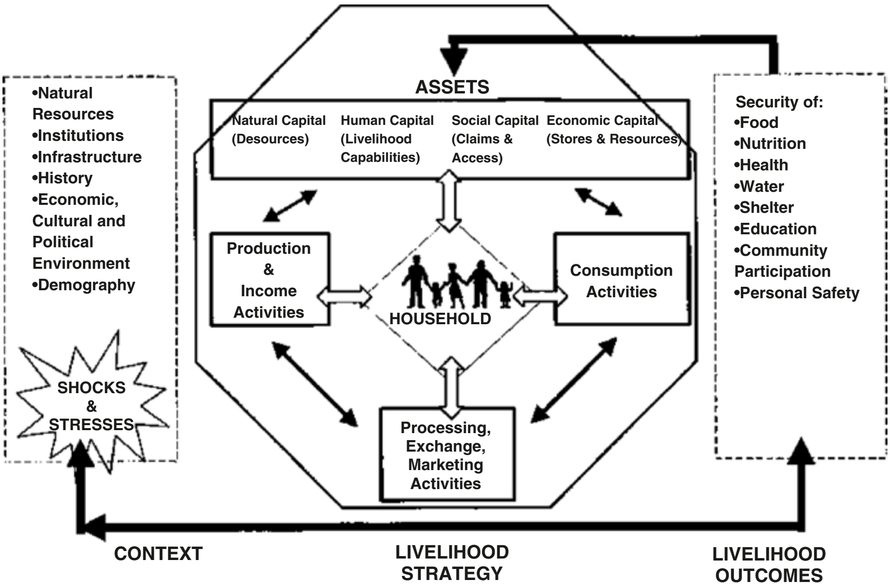

Fig. 11.1 A model of household livelihood security. (After Frankenberger and Drinkwater 1999; Carney 1998; Drinkwater 1994; Swift 1989)

health facilities, educational opportunities, housing, and time for community participation and social integration."

The livestock farming systems practiced by small and poor farmers in developing countries have lower productivity (per animal or land unit) than that in industrialized/developed world. Many reasons of lower productivity are enumerated. Management system present in small holder situation is low-or no-input system, allowing animals forage on own, feeding on waste, or plants which otherwise go unused. Mostly, relatively higher price of feed and low price of livestock products result in insufficient incentives for using purchased inputs in order to convert to intensive farming systems. The poor farmers mostly keep a mixture of livestock species and trade off specialization to get protected against risks. Resource constraints faced by the poor pig keepers are landlessness, information access, and financial and provisioning of services, and their various reasons for pig rearing include following:

- Food production.
- Income generation.
- Providing manure.
- Power production.
- Financial instruments.
- Enhanced social status.

9 Way Forward

Pigs play a major role in livelihoods of most of the backward and the poor, and therefore, inclusive development, based on their skills as well as resources, has the ability to contribute to both faster poverty reduction and rapid economic growth. Reconstituting the swine sector under livestock-related policy and the institutional framework, for ensuring that the policies, the program, and project permit men and women for taking full advantage of many livelihood (pig related) services rendered by livestock as well as for contributing to economic development, needs three important changes.

Firstly, the dominant "production, productivity, and the market access" narrative must be upgraded by a development paradigm which pays due regards to livelihood services rendered by livestock, encompassing both monetary and non-monetary services. To be effective, if resources be directed to ensure that a comprehensive and new livelihood-livestock (swine sector) development statement emerges, then future policies, the program, and project, by clinging to new pattern, will attempt for building on several livelihood (pig related) services provisioned by livestock, i.e., that livestock development including swine sector will be pro-poor and inclusive. Secondly, for being effective, the policies, the program, and project must be designed with the inclusive and the participatory process which includes conversation and example of evidence for addressing institutional dimensions. This means that resources must be invested towards making plan and implementing it for identifying/experimenting with new delivery mechanism and towards embracing the incentives which the poor livestock (pig) keepers have to respond to newer rule and regulation, as required for policy implementation. Thirdly, there is a need for better coordination among the livestock (pig) related policies at the state, the regional, and the national levels. This will avoid the duplication of efforts and wastage of already constrained resources, and, simultaneously, it will be ensured that the policy and program – at every level and in and out of the livestock (swine sector) domain – are not contradictory, the one thing that only can warrant a livelihood-enhancing and inclusive livestock sector (swine sub-sector) development.

10 Conclusion

The contribution of pigs towards the livelihoods of smallholder farmers around the world is well understood in spite of its complex nature. Nowadays, pigs have become an essential asset for resource-poor farmers, both those who are directly involved in agricultural farm production and also for non-farm rural poor households particularly who are dependent on affordable nutrition source. Livestock dependence is remarkably high across rural India especially in those parts having various degrees of vulnerability. The food and non-food products of livestock have been in the mainstay of rural small holders' livelihood and will continue to be the same if proper planning, policy back-up, and implementation of pro-poor livestock development projects/programs are stressed upon by the National Government. The genetic improvement of pig for increasing productivity will ensure the stocking of less number of animals for obtaining similar or more production. Fortification of breeding services and management in pig will be helpful in increasing the reach of these services to the large number of small-scale producers. Maintaining a value chain from the farm to fork through efficient and appropriate product processing, and effective marketing of the produce will be required for flourishing the livestock sector primarily owned by the small holders. Further, the subsistence-to-sustenance transition in case of pig rearing with its gradual increasing contribution to national economy should be strictly looked into with efficient and effective value chain management and opening up pro-producer marketing avenues that can warrant an inclusive and livelihood-enhancing (not only securing) small-scale pig production.

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Chapter 12
Revolutionizing Impact of Poultry Resources in Food Security and Rural Economy

R. N. Chatterjee, U. Rajkumar, and L. L. L. Prince

Abstract The impacts of poultry resources in food security and rural economy are discussed comprehensively in the present chapter. Poultry is the fastest-growing sector globally with significant growth rates over the years. About 300 estimated breeds of poultry contribute to the vast diversity and majority (63%) number of domesticated avian breeds. Poultry produce, eggs, and meat constitute a food source having high-quality and with essential macro and micronutrients and high bio-availability of vitamins. Eggs are having perfectly balancing nutrients to meet human dietary requirements. Food safety and security are very important issues globally which need priority in research, preservation, transport, etc. Antibiotic growth promoters should be strictly avoided to get rid of AMR problems. The potential contribution and impact of intensive and extensive production systems in rural and urban areas differs significantly. Poultry produce have multi-faceted benefits for the mankind; these need to be promoted extensively to tap the advantages of egg and poultry meat. Small-scale farming of poultry is a continuous source of income to the family especially in poor landless people across the globe. The value addition increases the return through nutritional manipulations, processing, and transgenesis which needs to be explored. Small-scale poultry farming contributes to many rural livelihood indicators such as income, quality nutrition, food security, savings, and insurance. Poultry farming provides assured income in exigencies such as crop failures, drought, sickness, etc. The impact of backyard poultry is not only limited to income generation but also to provide nutritional security in many of the underdeveloped and developing countries. Therefore, promoting poultry produce and its value addition enhances the impact of poultry products significantly, revolutionizing their role in global food security.

Keywords Food security · Small scale poultry farming · Rural economy

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_12

1 Introduction

Poultry sector is a fast-growing sector of agriculture globally experiencing 6–10% growth constantly over the last decade. Smallholder poultry growth has been substantial in underdeveloped and developing countries, while commercial poultry growth has been rapid in developed countries. Poultry provides major and cheap source of animal protein needs of the world population contributing significantly to the food bowel. Poultry produce, eggs, and meat are preferred without any religious taboo and customs across the globe.

2 Global Scenario

China is the largest chicken egg producer (with 40% production) in the world. Till 2008, 77.6% of China's egg production was coming from smallholding poultry farmers. The contribution from smallholding farmers by 2016 reduced to 56.9% (Yang et al. 2018). Global egg production was 1577.53 billion. Poultry contributes the largest share (38.4%) in global meat production and is the second most consumed meat. The annual per capita availability is 167 eggs with wide variability ranging from as low as 5 eggs in Niger-Africa to as high as 413 eggs in China-Asia (Ritchie and Roser 2017). Development and availability of high producing layer (310–340 eggs) and broiler (2.4–2.6 kg at 6 weeks) chicken for commercial sector and improved rural chicken varieties (100–180 eggs) for free-range small-scale rearing with standard package of practices are the primary factors for the spectacular growth in the sector. In 2021, the USA produced about 20.4 MMT of broiler meat, the highest in the world. China being the second largest producer of broiler meat is expected to produce 15.00 MMT of chicken meat in 2021 followed by Brazil 14.15 MMT, Russia 4.7 MMT, and India 4.2 MMT.

3 Indian Scenario

India produces about 105.20 billion eggs with a global share of 6.6% and ranks third in world egg production (FAO 2019). In India, poultry contributes about 50% of meat production with 4.05 MMT of chicken meat per annum (BAHS 2019). The global poultry has undergone a paradigm shift and transformed from a small-scale traditional backyard farming into a dynamic agri-based industry over the last five decades. The constant scientific innovations and untired efforts in upgradation and application of new technologies in the field of breeding, nutrition, health, and mechanization had paved the way for the multifold and multifaceted growth in poultry (Chatterjee and Rajkumar 2015). The per capita availability of eggs and chicken meat is about 79 and 3.5 kg, respectively, in India. The availability of egg and meat in majority of the countries is much below the recommended level of 180 eggs and 10.8 kg poultry meat per person per annum as per the Indian Council Medical Research.

4 Small-Scale Poultry Farming

Small-Scale Poultry Farming (SSPF) or backyard poultry is a traditional farming activity in rural areas with low inputs mainly depending on scavenging on the natural feed base available in the backyards with little supplementary feeding, provision of night shelter, and minimum healthcare practices (FAO 2007; 2010; 2014; Sharma and Chatterjee 2009; Rajkumar et al. 2021). The majority of farmers are engaged in rural poultry production mostly with indigenous native chicken or improved crossbred chicken and other poultry species (Alders and Pym 2009). SSPF is characterized by growing chicken in small numbers (20–50 or even more) for family consumption. In this system of rearing, the birds scavenge for feed in the backyard, consume insects and household waste, and also utilize the resources which are not directly useful to human beings or livestock. Generally, native chicken breeds are utilized for SSPF over the years wherein the productivity of birds is low. However, for increasing the productivity under the SSPF, the improved chicken varieties with higher potential for enhanced growth and egg production are used in the present modern-day village poultry farming. These improved varieties resemble the native birds with multi-colored plumage and have longer shanks, better productivity, better adaptability, and immunity, besides being able to perform on a low plane of nutrition (Rajkumar et al. 2021). The SSPF has a proven potential to alleviate poverty, generate subsidiary income, eradicate malnutrition, empower women, and provide employment in rural and tribal areas of the country (Sharma and Chatterjee 2009; Rajkumar et al. 2010; Rajkumar and Rama Rao 2015; Chatterjee and Rajkumar 2015; Chatterjee 2018; Islam et al. 2020). The birds in the free-range system scavenge for feed; sometimes supplementary feed are also provided to the birds. Shelter/housing is mostly required during the night time. Many a times, SSPF is commonly incorporated with crops and other livestock, as mixed production systems. The birds are self-propagating with broody hens. The indigenous birds lay 30–100 eggs per year. A small poultry production system accounts for 60–90% of the population in most of the developing countries across Asia and Africa and are found mostly in rural, resource-poor areas. In the early part of this millennium, the share of rural poultry is about 70–90% of poultry products in Africa (Alabi et al. 2006; Mack et al. 2005) and contributed about 20–30% of the total animal protein intake (Tadelle et al. 2003). There is a high demand for meat from indigenous non-descript chicken produced in rural areas, and due to their local taste preference they are sold in premium price. SSPF is primarily managed by rural women including different farming activities, marketing, income, and employment (Weaver 2009) leading to women empowerment.

In Africa, poultry is the source of income for the rural people which are mostly reared by women of the family (Thieme et al. 2014) in Zimbabwe, Ethiopia, and Zambia (Chatterjee 2011). It was found that village chickens are being reared mostly by women (Mapiye et al. 2008; Chatterjee 2011). Mostly, the men are involved in construction of the night-shelters or in slaughtering, while women are taking care of rearing of the birds and selling in these countries. The sale of poultry products is often the main source of income for households headed by women. In many Asian countries particularly in SAARC countries, village poultry production systems are important means of income generation. In both the continents (Asia and Africa) different poultry species constitute chicken, duck, guinea fowl, etc. Guinea fowl is a part of poultry rearing in African countries and ducks in coastal areas of India, Bangladesh, and China.

5 Genetic Resources

There are about 300 estimated breeds of poultry used globally in food production (Rege and Gibson 2003). Chicken breeds make up the majority (63%) of the total number of domesticated avian breeds. India is the home to the red junglefowl (*Gallus gallus*) which is considered to be the progenitor of the modern domestic chicken (*Gallus domesticus*). The *Gallus gallus* is distributed from the foothills of the western Himalayas to Northeastern India. At present 19 native breeds of chicken, two duck breeds, and one geese breed are registered in India (Chatterjee 2019). The registered indigenous breeds of chicken in India are Ankaleshwar, Aseel, Bursa, Chittagong, Danki, Daothigir, Ghagus, Haringhata Black, Hansli, Kadaknath, Kalasthi, etc. The home tract of these breeds is in different regions of India. The growth and production traits of these native breeds have been studied in detail (Chatterjee and Yadav 2008; Rajkumar et al. 2016; 2017). Research suggests that up to 30% of avian breeds were at risk (FAO 2007; FAO 2010; Sorensen 2010). It is important to conserve poultry genetic resources because indigenous poultry breeds are more resistant to disease and can survive in more extreme climatic conditions (Chatterjee 2019).

6 Egg and Poultry Meat as Valuable Food Source

Animal proteins are having better digestibility than the proteins from plant sources. Vitamin A is found as precursor reared for absorption in the animal source of food items. Iron and vitamin A are the causes of micronutrient deficiencies (Wong et al. 2017). Micronutrient absorption is of concern when the feed ingredients are mainly from the vegetables and cereals sources. High level of fiber, phytate, and oxalate decreases absorption of the micronutrients which are from plant-based diets. The bio-availability of nutrients from the egg and poultry meat is better than the plant sources.

Eggs and meat from chickens constitute a food source of high quality with densely packed essential macro and micronutrients, high bio-available iron, zinc, vitamin A, riboflavin, and vitamin B12, that are often deficient or absent largely in the vegetable diets, which is observed commonly in the rural areas (Wong et al. 2017). Poultry meat is also a good source of riboflavin, niacin, thiamin, vitamin A, vitamin B12, folate, iron, etc. (Williams 2007). Consumption of eggs and meat with such high concentration and bio-available nutrients is significant for infants and young children. Eggs are having perfectly balancing nutrients to meet human nutrient requirements; the small-scale poultry product utilizations are, thus, far superior than being a valued food source alone. Pregnant and lactating women need enhanced nutrient requirements than aging people.

One of the major food security apprehensions related to poultry products is the diversion of possible human food resources to livestock feed, particularly in case of monogastric animals. The scavenging feed resources utilized in extensive and semi-intensive poultry production transform feed ingredients in the environment that are less suitable for human consumption. These may be plant seeds, earthworms, and insects into palatable and nutrient-rich food for human being. Small-scale poultry production is regularly used as a part of integrated farming systems in many parts of Asia, Africa (Chatterjee 2011; Chatterjee 2017a, b), and Gulf countries.

7 Food Safety

Food safety is a very important parameter for all the poultry produce before introducing into the market. The poultry produce should meet all the food safety standards and guidelines mandated by the Government. There are certain diseases which are highly pathogenic like avian influenza (HPAI) and certain bacterial infections like Salmonella and Campylobacter which are zoonotic in nature and having health risks to human beings, especially when the chicken products are from sick birds. Many a times rearing of broilers in some of the countries encompasses antibacterial growth promoter (AGP). This creates problem for antimicrobial resistance (AMR) in human beings and other livestock species or fishes. Thus, AGP are given sometimes with feed material to get better growth in broilers. Therefore, food safety is very important, in the above circumstances. The poultry products must be free from zoonotic diseases. AGP should strictly be avoided to get rid of AMR problems.

8 Food Security

Food security commonly referred to food availability, domestic food production, stores, imports, and assistance at the national level and at the household level. Food availability refers to foods of optimum quality and those which are culturally and socially acceptable by a given population. Poultry are usually the most favored species in resource-poor rural and tribal regions of the globe. The poultry contribute to food chain through supplying nutrient-rich and acceptable products for human being in addition to providing manure to pest control (Wong et al. 2017). Poultry produce contribute significantly to the food security in terms of quality food products like eggs and chicken meat. The low input nature of scavenging or extensive system of small-scale poultry production makes it acceptable to the vulnerable or marginalized groups who are at high risk of food security in many Asian and African countries. The intensive systems of large-scale poultry need higher inputs and are often limited to rich people, and these birds are not suitable for scavenging system.

In general most parts of the developing and underdeveloped countries, the live birds and eggs are marketed in open-air or "wet" markets and in retail shops, where birds are slaughtered on sale (FAO 2007). Backyard poultry likely contribute to a larger proportion in areas where poultry farming is not developed. The village or backyard sector is commonly a traditional activity with local, native chicken breeds which are reared for both eggs and meat, often called as dual purpose chicken. Village or backyard production has been one of the potential activities which contribute to dietary protein and supplementary income for poor people (Acamovic et al. 2005; Sharma and Chatterjee 2009; Rajkumar et al. 2010). The high demand, niche market, and high market price for the local poultry reared in village backyard systems yield higher economic return and strengthen the rural economy in a big way.

9 Impact of Poultry Produce on Food Security

The poultry production system has been integrated with human livelihood ecosystem over thousands of years improving the rural economy and nutritional security of the rural poor (Alders and Pym 2009). The projected environmental and food impact system for increasing livestock production to meet the growing demand for animal source foods (Delgado 2003) is a big challenge. The potential contribution and impact of intensive and free-range small-scale production systems in rural and urban areas varies significantly. Moreover, intensive poultry requires reasonable costs for inputs, including stock, feed, labor, and health services as well as needs efficient marketing channels (Wong et al. 2017). In rural areas, access to markets, cold chains, and veterinary services is limited. There is a difference in rearing systems between the developed and developing countries. In developed countries the poultry rearing system is mostly under intensive system, while in developing countries poultry rearing systems are under the extensive, scavenging, under family poultry production system and commercial poultry system.

10 Promoting Poultry Produce

Poultry produce has a multi-faceted benefits for mankind; these need to be promoted extensively to tap the advantages of egg and poultry meat.

1. **Consumer education**: Most of the rural/tribal farmers do not know the benefits of high-quality egg and meat. Mass awareness campaigns utilizing mass media, radio, TV, exhibitions, etc. need to be organized regarding the health and nutritive values of the poultry produce especially in rural areas.
2. **Promoting egg consumption**: Egg at times is not considered as a vegetarian food. The people need to be convinced with the fact that egg is a vegetarian food. The commercial eggs are produced asexually without any embryo development as birds are not crossed for the purpose.
3. **Mid-day meal program**: The local poultry industry/authorities should convince the Government to introduce egg in their social welfare schemes especially in schools.
4. **E-marketing:** E-marketing/online marketing is the new business strategy adopted by many sectors to reach the consumers effectively. Nowadays the Internet and mobile are common in every household. Promotion of poultry business through the social media platform is an easy option to create consumer awareness and market influence through your social media pages. Strong networking among the people and provision of special apps for placing order online will boost the marketing opportunities.
5. **Home delivery**: Home delivery service is also one of the marketing options to boost the sale. This concept is significant because most of them need fresh eggs in the comfort of their home as they don't wish to go to the nearby grocery store.

11 Economic Contribution of Smallholder Poultry

Small-scale poultry farming is a continuous income source to the family especially in poor landless peoples across the globe. The experiences of backyard poultry economics from India are summarized below. The economics, estimated using the popular and improved rural chicken varieties like Vanaraja, is as in Table 12.1.

The SSPF is largely a subsidiary income-producing activity for the household in India rather than the main source of income. *Vanaraja* chicken farming was lucrative compared to the native chickens with 46.78% additional net returns from a unit of 20 birds with a benefit-cost ratio of 2.84 from Arunachal Pradesh, India. A total of Rs. 10,578 (USD 145) was earned as the net income from a unit of 20 *Vanaraja*

Table 12.1 Economics of Vanaraja bird under free-range conditions per pair of birds, one male and one female

Input			Output		
Sex	Age of the bird	Cost in Rs/(USD)*	Particulars/details of the bird	Receipt (Rs/USD)	Profit (Rs/USD)
Male	12 weeks	100 (1.37)	Bird at 12 weeks (1.5–1.8 kg) at Rs. 120/kg (USD 1.64/kg)	180–240/2.47–3.29	80–140/1.10–1.92
Female	72 weeks	225 (3.08)	Eggs: 100–110 at Rs. 5/egg	500–550/6.85–7.53	515–565/7.05–7.74
			Birds: 3.0 kg at Rs. 80 kg	240/3.29	
			Total	740–790/10.14–10.82	
Total profit from a pair of birds		325 (4.45)		920–1030/12.60–14.11	595–705/8.15–9.66

Source: Rajkumar et al. (2019)
*Includes cost of day old chick, feed, medicines, healthcare, etc

birds with a net profit of Rs. 529 (USD 7.25)/bird. The economics of *Vanaraja* (Rajkumar et al. 2010, 2018) and *Gramapriya* (Rajkumar and Rama Rao 2015, 2018) in a traditional backyard rearing system was estimated with the net profit per pair of birds (cock and hen) as Rs. 595–705 (USD 8.15–9.66) for *Vanaraja* and Rs. 820–930 (USD 11.23–12.74) for *Gramapriya* chicken, respectively. The average net returns from a unit of 20 birds were about Rs. 5200 (USD 71.2) from *Vanaraja* and about Rs. 7000 (USD 95.9) from *Gramapriya* rearing (Rajkumar et al. 2018) by considering the minimum sale price for the egg and chicken meat.

12 Value Addition

Value addition is the process of enhancing the value to a product or service through special processing, marketing, or making. All poultry products can be value added to increase the acceptability and nutritive value. In poultry, value can be added to eggs, meat, feathers, and even other parts that are usually thrown away. Value-added services, for example, restaurants that primarily serve poultry products, poultry parks, training on poultry, etc., can be offered. When value is added to the product, it increases the perceived value of the product. By adding value to chicken, a farmer gives more value to chicken and its products before offering it to the customers making them to pay more.

Value addition in poultry plays a significant role in growing the profits. The value addition may be through nutritional manipulations, processing, and transgenesis. Omega-enriched eggs and chicken meats developed by nutritional approaches are available for premium price in the market. Feeding the chicks with rich sources of omega fatty acids will aid in increasing the levels of omega 3 fatty acids in eggs and meat. Another approach is through biotechnological tools wherein the specific gene responsible for trait will be transgressed leading to transgenesis. However, this transgenic approach is still in nascent stage wherein research is being carried out. The commonly utilized method for value addition is processing of the poultry products. The low valued meats and by-products can be processed into highly nutritious finished products by using different technologies adding to the returns. Commercial meat products are emulsion-based products, sausages, smoked, restructured, etc. which can improve the acceptability by-products and increase the profits significantly. Similarly, different egg products can also be prepared and marketed.

13 Conclusion

SSPF contributes to many livelihood improvement indicators for rural people such as providing income, nutrition, food security, savings, and insurance. In terms of income generation and food security, the sale of those poultry and their products (e.g., egg, meat) is important. Poultry farming provides assured income in exigencies such as crop failures, drought, sickness, etc. Poultry farming also contributes to household food consumption, as many poor households rely on their own poultry products for animal protein needs and micronutrients such as iron and vitamin A. The impact is not only restricted to income earning but also to provide nutritional security in most of the underdeveloped and developing countries. Backyard poultry has the potential to reduce the malnutrition in the rural areas across the world. By promoting poultry produce and value addition, the impact of poultry products can be improved significantly revolutionizing their role in global food security.

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Chapter 13
Milk and Milk Product Safety and Quality Assurance for Achieving Better Public Health Outcomes

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Abstract The milk and milk products industry is one of the most important food sectors in many countries of the world. Dairy-derived foods can cater major nutritional requirement of people including infants and geriatric population. A significant demand-driven increase in milk production and dairy processing has been recorded. Products safety concern of this industry is very high, and it has so far been very successful in delivering chemically and microbiologically safe products. Nevertheless, the milk products processing sector has its challenges, starting from the farm to the point of consumption. In the entire dairy chain, from production up to consumption, different hazards (biological, chemical, or physical) may enter into milk either accidentally or intentionally. It has multiple sources of contamination, the pathways of which are very complex. Dairy animals can directly contaminate the milk by shedding pathogens into the milk. Milk can indirectly be contaminated during the milking and collection and transportation process. Milk products can further be contaminated by the equipment and time-temperature abuse of different treatments creating favorable conditions for microbial growth. Emerging pathogens are major threats for food safety. Problems like spread of antimicrobial-resistant pathogens through milk, cross contamination of undesirable microorganisms through biofilm produced on dairy equipment, and use of raw milk for cheese making result into more complex microbial hazards. Water, pests, soil, and heavy metals are also potential chemical contaminants that finally jeopardize the milk and milk products' quality and safety. Climate change is another challenge which is likely to increase microbial and chemical risks in milk system. Another man-made catastrophe that

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_13

affects dairy food quality and safety mainly in developing countries is food fraud. Strict vigilance by food safety authorities is highly essential to address such malpractice. Hence ensuring the quality and safety of milk and milk products before consumption attracts major concern starting from the producer level, and implication of different microbiological and chemical safety practices is key to maintain the safety and quality of milk and milk products for achieving better public health outcomes. Advancement of "omic science," chemical technologies, and gene-based tools enable to develop different novel technologies for rapid and reliable examination of technological, chemical, and microbial quality of milk and enumeration and eradication of milk hazards. The present chapter reviews microbiological and chemical risks for maintaining milk and milk products' safety and quality and discusses different ways of controlling the risks all along with the production and delivery chain.

Keywords Milk · Quality · Safety · Hazard · Food safety · Management

1 Introduction

Food safety and quality demands an escalating concern all over the world particularly when it comes to human health. In this regard, many countries have been running quality control programs for all food ingredients including that of animal sources. Recommendation made during the World Food Summit, 2002, about "the right of everyone to have access to safe and nutritious food," has been triggered to put diligent efforts to introduce, implement, and improve the food safety and quality control systems for its member countries (Kondakci and Zhou 2017). Global demand for milk and milk products has increased phenomenally due to its rich nutritional value. Consequently, worldwide milk production has increased remarkably from 522 million tons in 1986 to 798 million in 2016 (FAO 2018). Recently, the Food and Agriculture Organization of the United Nations (FAO) reported that about 6 billion people, mostly belonging to developing countries, consume milk and dairy products (FAO 2019). With the increasing demand for healthy and safe nutritious food worldwide, incidents of food fraud, adulteration, and unscrupulous attempt to taint food for deriving more economic benefit is also increasing day by day (Panghal et al. 2018). Food quality and safety-related mandates and allied legal obligations have been changed significantly in the last two decades. Food safety incidents often initiate at the early stages of the food production chain, sometimes beyond the scope of the manufacturers of the food. Numerous hazards may occur in these early stages of milk production and even during distribution, which may be more difficult to control than those arising during manufacturing stages. Therefore, "Farm to Table" concept, a holistic approach of food safety to ensure consumer's protection, has been adopted. A food item should conform to safety and quality requirements, with honest and accurate declaration on label as recommended by law (CFSAN 2007).

Milk, due to its complex chemical and biological compositions, may pose some threat for human health as well as economic losses, if not handled properly right from its production up to its consumption. In addition, adulteration of milk is an exasperating field problem, practiced perhaps to earn more profit or to check economic losses incurred due to "perishable" nature of milk. Hence, it is mandatory to monitor and control the quality of milk at every stage from the grass root level.

2 Quality and Safety Issues Associated with Milk and Milk Products

Milk quality encompasses assortment of chemical, physical, microbiological, and aesthetic characteristics that augment the acceptability of the milk products. Global incidents of foodborne diseases are increasing, and international food trade are disrupted due to recurrent disputes over food safety and quality requirements (Lemma et al. 2008; FAO 2010). The need of the hour is farm-to-table food safety and quality approach to ensure that milk and dairy products have been produced, processed, prepared, and handled according to the highest possible global food safety and quality standards. Thus, it becomes an obligation for producers, manufacturers, retailers, consumers, and regulators to maintain proper safety and quality along the entire dairy chain. Food safety hazards specific to milk and milk products occur chiefly due to chemical, biological, and physical hazards (Fig. 13.1). Inappropriate agricultural practices accompanied with poor hygienic activities at all stages of the food chain, dearth of proper preventive and controlling measures in food processing and preparation operations, contaminated raw materials, ingredients and water with residual harmful chemicals, unsatisfactory cleaning and sanitation, inadequate facilities for storage and distribution, etc. are chiefly responsible for prevalence of potential hazards in milk foods (Battu et al. 2004; Buncic 2006).

2.1 Chemical Hazards

Environment plays a significant role in milk production and milk products processing. Human activities are aggravating adverse environmental condition today. Foods are produced and grown with the help of pesticides, hormones, insecticides, antibiotic residues, fungicides, etc. These bio-chemical residues have high potentiality to provide different toxicological harm to the consumers. These contaminants are causes of fatal diseases to people like kidney damage, brain tumor, cardiovascular disease, hepatocellular carcinoma, hypertension, blue baby syndrome, leukemia, etc. (Volkmer 2005). Hormones and antibiotics are a matter of public health concern found in milk. Chlorinated pesticides, herbicides, detergent, disinfectants, sulfonamide drugs, anthelminthic drugs, polychlorinated biphenyls, polybrominated biphenyls, dioxins, heavy metals, mycotoxins, and somatotropin hormones are identified in milk and milk products at various stages of handling (Jensen 1995; Hubbert et al. 1996). These biochemical residues may pose serious public health concern.

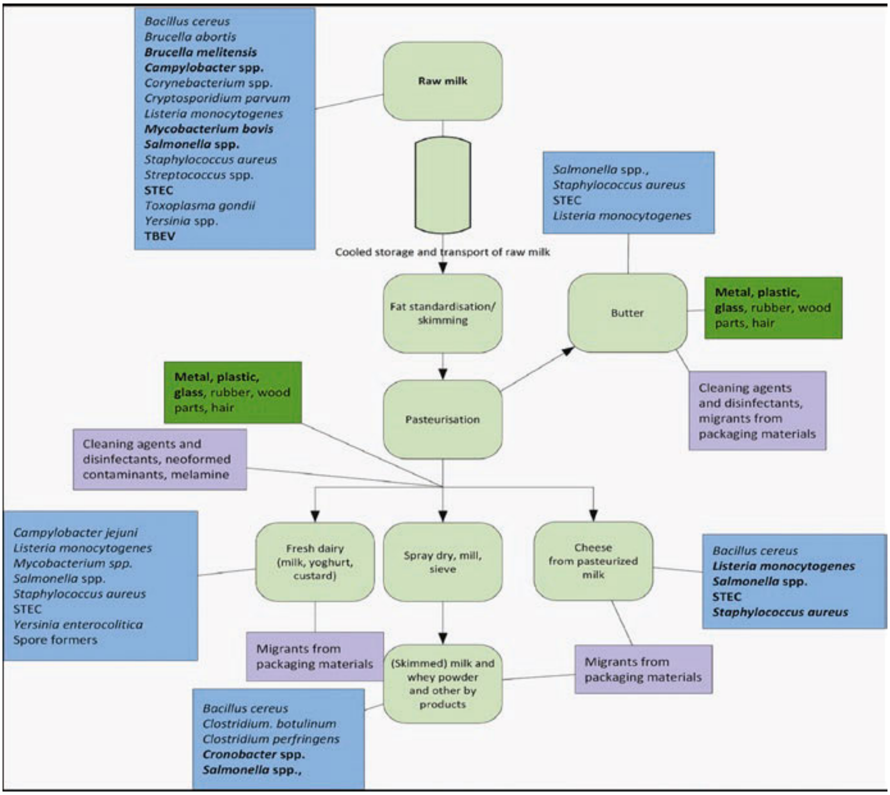

Fig. 13.1 Microbiological, chemical, and physical hazards at the dairy factory. (Source: van Asselt et al. 2017)

2.1.1 Sources of Chemical Residues in Milk and Milk Products

The major source of biochemical residues in milk and milk products comes from the milch animals when they are treated with antibiotic drugs and bovine growth hormones. Feeds are the source of pesticides, fungicides, herbicides, and insecticides. Mycotoxins are metabolized in the body of the animals by the molds. Heavy metals and toxic agents generally originate from the environmental pollution (Ray and Sen 2019).

2.1.2 Antibiotic Drugs

Residual quantity of antibiotic drugs used to treat the mastitis of the dairy cattle is generally found in the milk and milk products. Five major classes of antibiotics like tetracyclines (e.g., oxytetracycline, tetracycline, and chlortetracycline), amino glycosides (e.g., streptomycin, neomycin, and gentamycin), beta-lactams (e.g.,

Table 13.1 MRL of some antibiotic drugs in milk according to FSSAI regulations

No.	Drugs	Concentration mg/l
1	Sulphadimidine	0.025
2	Thiabendazole	0.1
3	Neomycin	2.5
4	Chlortetracycline	0.1
5	Ceftiofur	0.1
6	Ampicillin	0.01
7	Spectinomycin	0.2
8	Oxibendazole	0.01
9	Trimethoprim	0.01

Source: FSSAI (2006)

penicillins and cephalosporins), macrolides (e.g., erythromycin), and sulfonamides (e.g., sulfamethazines) are commonly used. These antibiotic drugs are absorbed by the animals through various routes like injection, orally taken with feed, inflammation on the skin with contact, and intramammary and intrauterine infusions. They are always expressed as the Maximum Residual Limit (MRL). Antibiotic drugs that are commonly used are given below (Table 13.1).

2.1.3 Bovine Growth Hormone

Bovine Growth Hormone or Bovine Somatotropin (BST) is a hereditarily built protein hormone either indistinguishable or like the normal bovine growth hormone created by pituitary organ. It increases milk production in dairy lactating cattle. Scientists demonstrate the dangers of colon, pancreas, endometrium, bosom, and prostate tumors are related to the elevated level of IGF-1, insulin, or both (Jones et al. 2011).

2.1.4 Steroid Hormones

Milk and milk products are the common sources of steroid hormones. The lipophilic hormones interact with the fat content of the milk and milk products. Ripening of cheese may influence the steroid hormone content while the processes like heating, cooling, and churning hardly affect. Molds and clotting enzymes are the main sources for testosterone during fermentation of different cheeses. Dairy products are the main source of estrogens in human diet (60–70%) (Ganmaa et al. 2004). The concentrations of estrogen and progesterone in various dairy products vary considerably depending on the composition of product (Table 13.2).

Table 13.2 The concentrations (ng/ml or ng/g) of progesterone and estrogens in milk and milk products

Hormones	Milk	Butter	Cream	Gouda cheese	Yoghurt
Esterone	0.13	1.47	0.26	0.17	0.16
17β-estradiol	0.02	0.3	0.03	0.03	0.02
Progesterone	9.81	141	48.6	44.2	13.3

Source: Malekinejad and Rezabaksh (2015)

2.1.5 Pesticides and Insecticides

The pesticides and insecticides directly affect milk and milk products through feed of the cattle. The most common and harmful examples are dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethane (DDD), chlorinated cyclodienes (aldrin, dieldrin, heptachlor, etc.), hexachlorocyclohexane (lindane), polychlorinated biphenyls (PCB), and dioxins (Table 13.3).

2.1.6 Mycotoxins

Mycotoxins are fungal metabolites found in the body of the animals at favorable temperature and humidity which are transferred to the milk and pose serious health concern to mankind after consumption. The major mycotoxin found in the milk is Aflatoxin M1 which is metabolized by the molds when the feed contains Aflatoxin B1. The improper storage, high damping during harvesting, and improper drying affect the production of Aflatoxin B1 (Ray and Sen 2019).

2.1.7 Nitrates and Nitrites

The main sources of nitrates and nitrites are fertilizers, rodenticides, and the chemical preservatives. Nitrates and nitrites are metabolized by the microorganisms from the nitrogen-containing dairy wastes and fertilizers used and animal feces. The dried form of nitrates and nitrites are white crystalline powder (Ray and Sen 2019).

2.1.8 Heavy Metals

Heavy metals have specific gravity higher than 5 g/cm^3, or atomic weight ranges between 63.5 and 200.6 g/mol, and are toxic to humans when ingested with a very small quantity. They are non-biodegradable or thermo-degradable and are ubiquitous in nature (Ismail et al. 2014).

Consumption of heavy metals like Pb, Cd, Cu, and Zn, entering in the body through food chain, poses serious health threat to the newborn and infants.

Table 13.3 Incidence of pesticide residues (mean level) in milk and milk products

Pesticides	Types of dairy products	Mean level (mg/kg of fat)	References
Dieldrin	Ras cheese	0.0039–0.0068	Aman and Bluethgen (1997)
	Damietta cheese	0.0025	Aman and Bluethgen (1997)
Dichlorodiphenyltrichloroethane (DDT)	Milk	0.159	Waliszewski et al. (1997)
	Butter	0.049	Waliszewski et al. (1997)
	Milk powder	0.0546	Aman and Bluethgen (1997)
Hexachlorobenzene (HCB)	Raw milk	0.016	Martinez et al. (1997)
	Milk powder	0.00656	Aman and Bluethgen (1997)
	Ras cheese	0.0037	Aman and Bluethgen (1997)
	Damietta cheese	0.0045	Aman and Bluethgen (1997)
	Spanish pasteurized milk	0.007	Martinez et al. (1997)
Hexachlorocyclohexane (HCH)	Milk	0.094	Waliszewski et al. (1997)
	Spanish pasteurized milk	0.015	Martinez et al. (1997)
	Milk powder	0.0149	Aman and Bluethgen (1997)
	Ras cheese	0.00865	Aman and Bluethgen (1997)
	Damietta cheese	0.0115	Aman and Bluethgen (1997)
	Butter	0.093	Waliszewski et al. (1997)
Aldrin-dieldrin	Cheese	0.0002	Martinez et al. (1997)
	Milk	0.0074–0.0271	Aman and Bluethgen (1997)
	Milk powder	0.0025	Aman and Bluethgen (1997)

2.2 *Microbial Hazards*

It is an age-old concept that absolutely sterile milk, as it secretes from udder, gets contaminated from external sources like environment, the mammary gland skin, or the oral cavity of the offspring (Addis et al. 2016). But in recent days, several studies have revealed that apart from external sources of contamination, endogenous routes may also be vital sources of bacterial transmission in milk. Therefore, microorganisms colonized in different anatomical locations other than udder may somehow enter the mammary gland through endogenous route. The intestinal bacteria may transfer to the mammary gland in cows, and subsequently may shed into the milk (Young et al. 2015). A number of microorganisms can also enter into the milk during subsequent processing, storage, and transportation. Common routes of microorganisms accessing milk at various stages are clustered in Table 13.4. Thus, it is important to assess the composition of the raw milk microbiota and its impact on the composition and quality of the milk and its derived products (Addis et al. 2016; Quigley et al. 2013a).

2.2.1 Spoilage Causing Bacteria in Milk and Milk Products

The nutritious content of milk not only offers nourishment to its consumers, but it also allows growth of numerous heterogeneous types of microorganisms responsible for spoilage of milk and milk products (Table 13.5). Raw milk is highly perishable in nature, due to development of acidity within few hours when kept at ambient temperature, as a result of rapid growth of Gram-positive lactic acid bacteria (LAB) present in the milk (Wouters et al. 2002). Major LAB genera like *Lactococcus*, *Streptococcus*, *Lactobacillus*, *Enterococcus*, and *Leuconostoc* are present in fresh raw milk, along with several other Gram-positive genera like *Bacillus*, *Propionibacterium*, *Microbacterium*, *Micrococcus*, and *Staphylococcus* (Quigley et al. 2013a; Von Neubeck et al. 2015). With the advancement of "omic science" and molecular techniques, the microbial composition in raw milk has been revealed as more complex than perceived earlier (FAO 2006; Zhang et al. 2019).

Apart from the Gram-positive bacteria mentioned above, Gram-negative bacteria associated with milk include *Pseudomonas*, *Acinetobacter*, *Psychrobacter*, *Chryseobacterium*, *Bacteroides*, *Porphyromonas*, *Comamonas*, *Fusobacterium*, *Aeromonas*, *Enterobacter*, *Hafnia*, *Klebsiella*, *Ralstonia*, *Sphingomonas*, and *Stenotrophomonas* (Porcellato et al. 2018; Fusco et al. 2020). Psychrotrophic and spore-forming bacteria can proliferate comfortably in milk even during refrigerated storage, and due to their ability to produce extracellular heat-resistant enzymes such as protease (peptidase and proteinase), lipases, and phospholipase, they contribute significantly to spoilage of even ultrahigh temperature (UHT) treated and sterilized milk and other dairy products (Stoeckel et al. 2016; Machado et al. 2017). Post-pasteurization contamination is one of the major hurdles in the milk industry, and 50% of fluid milk can become contaminated by heat labile bacteria after pasteurization (Martin et al. 2018). Post-pasteurization contaminants are identified as *Pseudomonas* spp., the coliforms, a group of enterobacteria capable of utilizing lactose, and other psychrophilic Gram-negative bacteria and Gram-positive, spore-forming bacteria, like *Bacillus* and *Paenibacillus*.

Concerted impact of effective controlled temperature during storage of raw milk, efficient heat treatment, and efficacious sanitation and cleaning-in-place practices adopted by dairy industry can satisfactorily restrict the microbial growth of the milk and milk products.

Table 13.4 Major sources of microorganisms contaminating milk and milk products

Step in dairy chain	Source of contamination	Implication for milk safety	Predominant microflora
From animal	Disease (mastitis, bovine tuberculosis, hay fever, etc.)	Increased shedding of pathogens directly into milk from diseased animals (including asymptomatic carriers)	Pathogenic organisms of zoonotic source: Coagulase negative staphylococci, *Staphylococcus aureus*, *streptococcus* species, *bacillus* species *S. agalactiae*, and *E.coli*, *Mycobacterium bovis*, *Brucella abortus*, *Coxiella burnetii, Mycobacterium avium* subsp. *paratuberculosis*
	From mammary gland (without disease manifestation)		*Staphylococcus* spp., *streptococcus*, *bacillus* spp., *micrococcus*, *Corynebacterium*, coliforms
From farm environment	Housing, bedding, soil, air	Poor housing and husbandry practices increase the risk of udder contamination due to high stocking, concentration of waste, stress and soiled bedding, leading to contamination of milking environment and raw milk	Psychrotrophic bacteria like *pseudomonas*, aerobic spore-forming organisms *bacillus* spp.
	Feed and water quality	Contaminated or poorly prepared feed may increase fecal shedding of pathogens into milk and milking environment Increased risk of milk contamination can result from using poor-quality water for stock drinking, teat washing, and cleaning	Coliform organisms, protozoa, *toxoplasma gondii*, butyric acid bacteria, clostridia spores, *pseudomonas* spp.
Milk collection	Milking practices: Contaminated udder, teat, skin, milking equipment, personal hygiene	Poor milking practices, including dirty, chapped, or cracked teats, udder, insufficient cleaning and maintenance of milking equipment, and poor personal hygiene can lead to direct contamination of raw milk with pathogens	*Salmonella* species, *listeria monocytogenes*, Shiga toxin producing *E.coli*, *campylobacter jejuni*, *Yersinia enterocolitica*, and *clostridium* spp., biofilm-producing microorganisms

(continued)

Table 13.4 (continued)

Step in dairy chain	Source of contamination	Implication for milk safety	Predominant microflora
Raw milk storage	Availability and efficiency of cold storage facilities	Inappropriate temperature control of raw milk, coupled with the usually high temperature in the region and erratic power supply	Psychrotrophic organisms like *pseudomonas* spp., *bacillus* spp. coliform organisms, other gram-negative rods
Traditional milk processing	Pasteurization/thermal treatment, fermentation practices, condensation, cream separation, drying	Inadequate pasteurization may not be able to eliminate pathogens in already contaminated milk and may even encourage the faster growth of pathogens Spontaneous fermentation (without properly defined starter culture), coupled with poor time/temperature control can expose fermented products to pathogenic organisms	Thermoduric organisms, microbacteria spp., *micrococcus* spp., *enterococcus* spp., spore-forming organisms, thermophilic streptococci, thermophilic LAB, coliform organisms, gram-negative rods, *enterococcus* spp., spore-forming organisms
Post processing contamination	After the control point of processing, i.e., heat treatment (pasteurization, or equivalent)	Poor sanitation of processing environments, failure of refrigerated storage, inappropriate packaging materials and poor hygiene, transporting of milk and milk products without a proper cold chain enable growth of pathogens; improper storage and distribution by distributors and retailers allow the rapid growth of spoilage-causing bacteria and pathogens in raw milk, poor hygienic practices by milk processors	Psychrotrophic spore-forming organisms, lactic acid bacteria, *streptococcus* spp., *Staphylococcus aureus*, *salmonella* spp., *enterococcus* spp., enterotoxigenic *E.coli*
Consumer practices	Temperature of home storage Adherence to handling instructions and good personal hygiene	Poor refrigeration during home storage of both raw and processed milk can accelerate the proliferation of pathogenic microorganisms Lack of proper hygiene and non-adherence to handling instructions can lead to contamination and proliferation of pathogenic microorganisms	Spore-forming organisms, coliforms, psychrotrophic organisms, molds

Source: Owusu-Kwarteng et al. (2020); Hayes and Boo (2001); Chamber (2002), Meng et al. (2017)

Table 13.5 Major microbial spoilage of milk and dairy products

Kind of defect	Cause	Related microorganism
A. Pasteurized, sterilized, UHT milk, condensed milk		
Bitty cream	Activity of phospholipases and proteinases and fat destabilization	*Bacillus* spp.
Gelation	Thermo-resistant proteinases	Psychrotrophic bacteria (*pseudomonas*, *Flavobacterium*, *micrococcus*, *bacillus*, *Enterobacter*, *Aeromonas*, and *Alcaligenes*)
Sourness	Lactic acid production	Aerobic spore-forming organisms, *Bacillus cereus*, lactic acid bacteria
Undesirable flavor: Unclean, fruity, bitter, rancid, yeasty	High concentration of free fatty acids due to activity of thermostable lipases; bitter peptides due protein hydrolysis by the activity of heat stabile proteinases	*Pseudomonas fragi*, *P. fluorescens*, psychrotrophic lipolytic and proteolytic bacteria, *bacillus* spp.
Caramel and malty flavor	Due to activity of oxidase enzyme production of 3-methylbutanol	*L. Lactis* var. *maltigenes*
Acid coagulation of milk	Increase of free fatty acids and casein hydrolyses, destabilizing the casein micelles	*Bacillus* spp.
Sweet curdling	Due to the production of an extracellular rennin like enzyme	Psychrotrophic spore-formers *Bacillus subtilis*, *Bacillus cereus. Proteus* spp.
Ropiness	By slime capsular polymers that are located on the surface of bacterial cells, action of polymerase enzyme	*Alcaligenes viscolactis*, m*icrococcus freudenreichii* (surface ropiness); *Enterobacter aerogenes* (ropiness near the top); *Enterobacter cloacae*, *E. coli*, and *bacillus* (ropiness throughout the milk
B. Powder milk		
Shorter shelf-life, rancidity, and bitterness	Bacterial proteinases and lipases and increase of free fatty acid	*Bacillus* spp., thermoduric micrococci, enterococci, *S. thermophilus*
C. Cheese		
Destabilization of the natural plasmin system of milk. Affect the quality of cheese, flavor, and texture development, and reduce the yield of the curd	Activity of lipases and proteinases remain in curd, that cause hydrological changes during ripening and result into the spoilage of milk and dairy products	Psychrotrophic spp.

(continued)

Table 13.5 (continued)

Kind of defect	Cause	Related microorganism
Change coagulation time and quality of curd (fragile and less compact)	Shorter coagulation time/ higher concentration of free amino acids (due to bacterial proteinase activity) which stimulates starter culture growth. Longer coagulation time/ higher concentration of free fatty acids (bacterial lipases) which inhibits starter culture growth	Proteolytic and lipolytic bacteria
Undesirable flavor: Rancid taste in hard cheeses (ripening) Bacillus spp.	Due to lipase activity, free fatty acids increase	*Bacillus* spp.
Bitterness and off-flavors	Due to short-chain fatty acids	Lipolytic bacteria
Changes of texture and flavor: More firm gel and higher viscosity, more pronounced syneresis	Heat stable enzymes	Psychrotrophic organisms
Lipolytic changes (free fatty acid): Atypical flavor as bitter, rancid, unclean, and fruity	Heat stable lipase enzyme	Psychrotrophic microorganisms
Creams and butter		
Reduced shelf-life Rancidity and off-flavor Fruity, bitterness, soapy	High concentration of lipases and proteinases in milk (cream) High conc. Of free fatty acids (C4–C6; C110–C12)	Psychrotrophic *Pseudomonas* spp. *P. fragi* *P. fluorescens* *Bacillus* spp.
Gas production (early and late blowing)	Abnormal fermentation of lactose of milk or cream into gas and acid. These are called "early gas producer" that lead to blowing condition	*E. coli*, *E. aerogenes*
	Anaerobic fermentation due to butyric fermentation that produces excessive H_2 and CO_2 gases	*Clostridium butyricum*, *clostridium sporogenes*

Source: Hayes and Boo (2001); Chamber (2002)

2.2.2 Pathogenic Bacteria in Milk and Milk Products

Pasteurization of milk is an age-old process employed to destroy pathogenic microbiota of milk. The time-temperature combination of this process was initially designed to inactivate relatively heat-resistant, nonspore-forming pathogen *Mycobacterium tuberculosis*. Nowadays, the pasteurization process has been manipulated to attain a 6-log reduction of *Coxiella burnetii* (van Asselt et al. 2017). Unhygienic production of raw milk, inefficient thermal processing, inferior quality of packaging, improper storage and distribution, and faulty practices of consumption of milk and milk products may result into onset of diseases to the consumers due to transmission of a variety of pathogenic microorganisms to processed milk (Table 13.6).

Few emerging pathogens occurring in milk and milk products include Shiga toxin-producing *Escherichia coli* (STEC), coagulase-negative enterotoxin producing *Staphylococcus* spp., *Listeria monocytogenes*, *Campylobacter* spp., *Salmonella* spp., coagulase-positive *Staphylococcus* spp., and atypical *Listeria innocua* strain (FDA 2013; FSANZ 2014; EFSA and ECDC 2018). Methicillin-resistant *Staphylococcus aureus* is another big threat (Riva et al. 2015; Titouche et al. 2019). *Campylobacter* spp. are also responsible for diarrhea (WHO 2018).

2.2.3 Fungal Population in Milk

The population and types of yeasts and molds present in raw milk depend upon the physiological condition of dairy animals, feeding, season, and weather (Callon et al. 2007; Vacheyrou et al. 2011). *Kluyveromyces marxianus*, *Kluyveromyces lactis*, *Rhodotorula mucilaginosa*, *Debaryomyces hansenii*, *Geotrichum candidum*, *Geotrichum catenulate*, *Pichia fermentans*, *Candida sake, Candida parapsilosis*, *Candida inconspicua*, *Trichosporon cutaneum*, *Trichosporon lactis*, *Cryptococcus curvatus*, *Cryptococcus carnescens*, and *Cryptococcus victoriae* are the commonly occurring yeast species in raw milk (Delavenne et al. 2011). By virtue of culture-independent approaches, two new species of yeast, namely, *Torrubiella* and *Malassezia*, have been identified from raw milk (Delavenne et al. 2011). Molds are also obtained in raw milk comparatively lesser in number. *Fusarium merismoides*, *Penicillium glabrum*, *Penicillium roqueforti*, *Aspergillus fumigatus*, as well as species of *Cladosporium* and *Torrubiella*, *Geotrichum*, and *Mucor* are the most commonly detected molds in raw milk (Quigley et al. 2013b; Lavoie et al. 2012). Though molds are useful in developing few characteristics like body, texture, and flavor of cheese and fermented milks, few molds can produce mycotoxin that may be harmful for human (Creppy 2002; Murphy et al. 2006). *Aspergillus*, *Alternaria*, *Fusarium*, and *Penicillium* are the most important genera of food mycotoxigenic fungi. The mycotoxins like aflatoxin, trichothecenes, zearalenone, fumonisins, and ochratoxin have the greatest public health importance (Quigley et al. 2013b).

2.2.4 Viral Load in Milk and Milk Products

Raw milk or milk products produced from raw milk especially in developing countries, where low sanitary conditions prevail, may result into milk-borne viral infection. Inactivation of viral load in milk may require little higher temperature-time combination of heat treatment. In the pre-vaccination era, poliomyelitis outbreak

Table 13.6 Major microbial pathogens associated with milk and milk products

Organisms	Disease
Enterobacteriaceae:	
E. coli – Verotoxin-producing (VTEC) – Shiga toxin-producing (STEC), e.g., (*E. coli* O157:H7) – Enterohemorrhagic	Gastroenteritis, hemolytic uremic syndrome
Salmonella typhi	Gastroenteritis, typhoid fever
Yersinia enterocolitica (psychrotrophic)	Gastroenteritis
Other gram-negative bacteria:	
Aeromonas hydrophila (psychrotrophic)	Gastroenteritis
Brucella spp. *(B. melitensis)*	Brucellosis (Bang's disease)
Campylobacter jejuni	Gastroenteritis
Pseudomonas aeruginosa	Gastroenteritis
Helicobacter pylori	
Gram-positive spore-formers:	
Bacillus cereus (some strains are psychrotrophic)	Gastroenteritis
Bacillus anthracis	Anthrax
Clostridium perfringens	Gastroenteritis
Clostridium botulinum (type E is psychrotrophic)	Botulism
Gram-positive cocci:	
Staphylococcus aureus	Emetic intoxication
Methicillin-resistant *S. aureus* (MRSA)	Emetic intoxication
Streptococcus agalactiae	Sore throat
Streptococcus pyogenes	Scarlet fever/sore throat
Streptococcus zooepidemicus	Pharyngitis, nephritic sequelae
Miscellaneous gram-positive bacteria:	
Corynebacterium spp.	Diphtheria
Listeria monocytogenes (psychrotrophic)	Listeriosis
Mycobacterium bovis	Tuberculosis
Mycobacterium tuberculosis	Tuberculosis
Mycobacterium avium ssp. *paratuberculosis*	Johne's disease (ruminants)
Rickettsia:	
Coxiella burnetii	Q fever
Viruses:	
Enterovirus, including polioviruses, rotaviruses, Coxsackie viruses	Enteric infection
Hepatitis virus	Infectious hepatitis
Fungi:	
Molds	Mycotoxicoses
Protozoa:	
Entamoeba histolytica	Amebiasis
Giardia lamblia	Giardiasis
Toxoplasma gondii	Toxoplasmosis

Source: Hayes and Boo (2001)

with polioviruses was reported to be associated with milk contamination. Complete inactivation of polioviruses in water, milk, and yoghurt was reported to occur by HTST pasteurization extended up to 30 s (Strazynski et al. 2002). However, in most cases, post processing contamination of human pathogenic viruses is the major reason for viral pathogenesis. Tick-borne encephalitis virus was reported to be present more in goat and sheep milk as compared to bovine milk (Balogh et al. 2012). Insulating effect of milk fat was thought to provide heat stability of the viruses in milk (Streinu-Cercel et al. 2012).

2.3 Physical Hazards

Any foreign objects that can enter into the milk causing injury or illness to the consumers are called physical hazards. The most important physical hazards to milk and milk system may include metal (ferrous and non-ferrous), plastic, ceramic and glass particles, insects/pest parts, wood fragments, and any extraneous matters that enter accidentally from personnel like hair, jewelry, buttons, etc. and other extraneous materials that may render food unsafe (Ahmedsham et al. 2018).

3 Food Safety Challenges in Dairy Foods

Presence of hazards, especially microbial content of milk, may pose more serious threat due to some acquired vulnerabilities. While several regulations and techniques have evolved to control different types of microbial risks in milk and milk products, special attention is still required to address few more challenges like biofilm formation on surfaces of milk processing equipment, antimicrobial resistance of pathogenic bacteria present in milk, and also impact of climate change on the microbial contamination in dairy industry.

3.1 Biofilm Formation: A Stubborn Challenge

The microbial biofilm has received relatively little attention in the dairy industry (Marchand et al. 2012). Microorganisms may adhere to the surfaces of apparatus used in food and beverage processing industries even after cleaning and disinfection operations. These adherent microorganisms form complex structures due to production of exopolysaccharides and form biofilm Weber et al. (2019). These biofilm forming microbial population appear to contaminate the milk processed in subsequent batches. Spores and vegetative bacterial cells may be found on every surface of food handling equipment. Contamination from biofilm may result into finished products with shorter shelf-life or public health implications (Lindsay et al. 2002;

Brooks and Flint 2008). Both spoilage causing and pathogenic bacteria like *Pseudomonas aeruginosa*, *Salmonella typhimurium*, *Yersinia enterocolitica*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Klebsiella pneumoniae* and spore-forming bacilli are reported to form biofilms (Teh et al. 2014; Moretro and Langsrud 2017). The heat-resistant spoilage enzymes like proteases and lipases can also reduce the shelf-life of UHT milk (Teh et al. 2014). Chemical treatments with ammonium compounds, sodium hypochlorite, peracetic acid, and ozone are the most effective sanitizers for eliminating attached cells of biofilm. Cellulases, proteases, glycosidases, DNAses, bacteriophages (such as P100), bacteriocins (nisin), biosurfactants (lichenysin or surfactin), and plant essential oils (citral- or carvacrol-containing oils) are the effective means of enzymatic disruption of biofilm-forming cells (Galié et al. 2018). Use of peptide-based coating, nanoparticles with different metal oxides, hydrogels, liposomes, nanocomposites, and antimicrobial polymers can prevent biofilm formation in the dairy industry (Galié et al. 2018; Gupta and Anand 2018; Friedlander et al. 2019).

3.2 Antimicrobial Resistance of Milk Pathogens: A Clinical Threat for Consumers

It is a common veterinary practice to administer antimicrobials to the dairy animals for treatment as well as management purpose. In dairy cattle, mastitis, brucellosis, and tuberculosis are the most frequent bacterial diseases, which are mainly treated by using antimicrobial substances, particularly antibiotics. Antimicrobial therapy is also given growth promotion or increased feed efficiency. Extensive use of such antimicrobials for disease control and enhancement of production of dairy animals also leads to the most challenging threat called Antimicrobial Resistance (AMR) acquired by the target pathogens. It has been also reported that the antimicrobial resistance genes (ARGs) often get transferred from target pathogens to other organisms through horizontal gene transfer (HGT), posing more complex threat for food safety. As a result the potential pathogenic organisms are also acquiring multidrug resistance (MDR) resulting into increased mortality of human and animals (Tóth et al. 2020). Recently, antibiotic-resistant infections in more than 2.8 million people including death of more than 35,000 people have been reported in the USA each year (CDC 2019). Based upon the severity, CDC has classified few important antimicrobial-resistant organisms into three categories (Table 13.7).

3.3 Climate Change: An Adverse Impact on Milk Quality

Climate change is now a great concern that affects today's world in different ways. Variability in natural climate has been observed over comparable time periods. Unusual climatic instability is observed nowadays in the form of rise in mean average seasonal temperature, frequent draughts, and excessive precipitation within few

Table 13.7 Classification of antimicrobial-resistant pathogenic organisms based upon severity of threats

Urgent threats	Serious threats	Concerning threats	Watch list
Carbapenem-resistant Acinetobacter *Candida auris* (*C. auris*) *Clostridioides difficile* (*C. difficile*) Carbapenem-resistant Enterobacteriaceae (CRE) Drug-resistant *Neisseria gonorrhoeae*	Drug-resistant *campylobacter* Drug-resistant *Candida* Extended-spectrum beta-lactamase (ESBL)-producing Enterobacteriaceae Vancomycin-resistant enterococci (VRE) Multidrug-resistant *Pseudomonas aeruginosa* Drug-resistant nontyphoidal *salmonella* Drug-resistant *salmonella* serotype Typhi Drug-resistant *Shigella* Methicillin-resistant *Staphylococcus aureus* (MRSA) Drug-resistant *Streptococcus pneumoniae* Drug-resistant tuberculosis	Erythromycin-resistant group A *streptococcus* Clindamycin-resistant group B *streptococcus*	Azole-resistant *aspergillus fumigatus* Drug-resistant *mycoplasma genitalium* Drug-resistant *Bordetella pertussis* (B. pertussis)

Source: CDC (2019)

days during rainy season. Climate change has also brought alteration of ocean properties, such as surface temperature, acidification, and level of dissolved oxygen (EEA 2017). Due to the climate change, alteration in different weather variables like average environmental temperature, relative humidity, and average rainfall beyond normal seasonal variation may happen (Pang et al. 2017). In turn, climate change may affect the microbial profile of dairy products by manipulating the raw milk microbiota and their metabolites (Fig. 13.2).

Increase in atmospheric temperature may induce heat stress in the lactating animals resulting in changes in physiological conditions as well as immune functions (West 2003; Lacetera 2019) that lead to disease susceptibility of (Dahl et al. 2020). Higher temperature and humidity may induce production of mycotoxin (Paterson and Lima 2010), insect-borne transmission of animal diseases (Maclachlan and Mayo 2013), and growth of pathogens and molds. Global warming and climate change may set another challenge of maintaining cold supply chain during storage, transportation, and distribution of highly perishable milk and milk products, and thus it may affect the spoilage risk of dairy products (James and James 2010). Quantitative Microbial Risk Assessment (QMRA) models have been developed to develop climate change-resilient mitigation strategies (Janevska et al. 2010; Jacxsens et al. 2010; Pang et al. 2018).

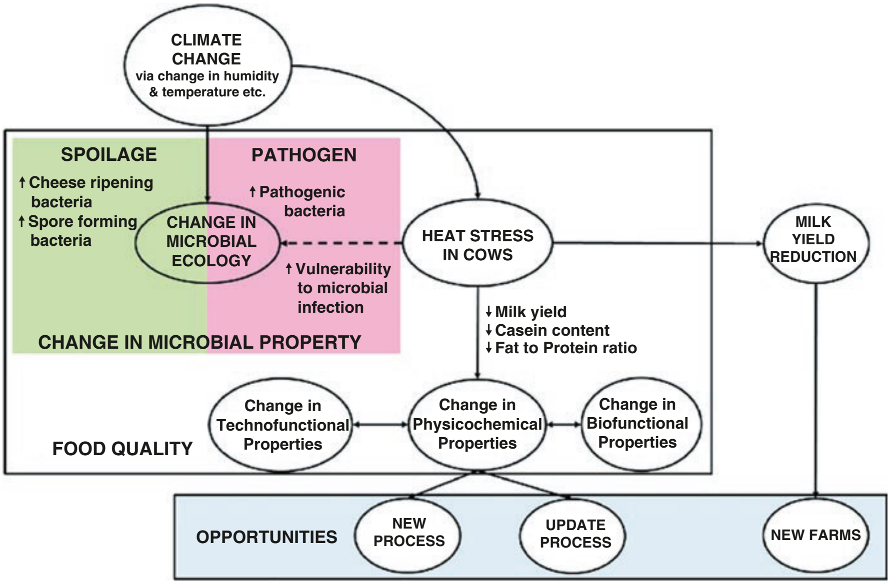

Fig. 13.2 Possible effects of climate change on raw milk. (Source: Feliciano et al. 2020)

4 Quality Assurance Aspects of Milk and Milk Products

Quality assurance is totally a planned activity to provide satisfactory assurance that a certain food item is fulfilled with the quality requirements (Ahmedsham et al. 2018). Food quality is a multifaceted perception that is inseparably related to food safety. The safety and quality management in a dairy industry focuses on the customer-consumer interfaces. Several processes lie at each interface. The dairy industry requires proactive procedures which provide impetus for implementing different safety and quality management systems like ISO (International Organization for Standardization), HACCP (Hazard Analysis and Critical Control Points), Six/Nine Sigma, etc. for ensuring delivery of safe dairy products to the consumers.

4.1 Food Safety Practices

Milk and milk products may be contaminated through numerous fronts that include unhealthy practices at dairy farms and storage practices, workers and equipment, atmosphere, and production, processing, packaging, and distribution. It is thus necessary for milk producing farms and production entities to comply with GMP, GHP, and HACCP guidelines. The maintenance of hygiene throughout the dairy supply chain is highly required to minimize or prevent the contamination caused by pathogens and bacteria, conforming to the standards of food safety and providing quality and safe dairy foods to the consumers.

4.1.1 Hygienic Practices at Dairy Farm

It is necessary to maintain appropriate hygiene at all places like building premises, animal shed, milk parlor, and milk storage room and also during all activities of farm, such as cleaning of animals and animal sheds, feeding of healthy feeds and fodders, and storing of milk, besides personnel hygiene. Proper hygiene at dairy farm can supply clean milk for further processing and thus reduce the chances of microbial or other contamination.

4.2 Quality Management System

Food quality, a multifaceted concept, is intricately related to food safety. Dairy foods must fulfill nutritional requirements on one hand and safety on the other hand to gratify the vast consumers especially the most vulnerable, the infants and geriatric communities. It's a mammoth task for a dairy industry to comply all the requirements in an effective manner. That triggers dairy industries to adopt quality management system. The International Organization for Standardization (ISO) has laid the international standards and management practices which help an organization to establish, implement, maintain, and continually improve a management system efficiently. The ISO certification is a very important strategy for both dairy production units (Farms) and processing units (Factories) as it provides the sense of security to the customers and other stakeholders about the quality and safety of the products (www.iso.org).

4.2.1 ISO 9000

ISO 9000 is the well-recognized quality management system for any industry. The system has been reviewed and upgraded periodically, and thus ISO 9000 series includes:

- **ISO 9000:2005** covers the basics of what quality management systems are and also contains the core language of the ISO 9000 series of standards.
- **ISO 9001:2008** is intended for use in any organization irrespective of size, type, or product or service.
- **ISO 9004:2000** covers continual improvement and guidance on what one could do to enhance a mature system.
- **ISO 9000:2015** defines fundamental concepts and principles of quality management which are globally applicable for the organizations aiming at sustainable

success at each and every step of operations and customers seeking confidence to get quality products. ISO 9000:2015 specifies the terms and definitions that apply to all quality management and quality management system standards developed by ISO/TC 176.

4.2.2 Total Quality Management (TQM)

Total Quality Management (TQM), another management tool of quality assurance program, is applied to dairy operations to help the dairy producers gain a better understanding of their entire production process, which impacts milk quality and food safety. Keys to the success of such strategy include maintaining written records, monitoring, and expertise to detect variations in the production process that affect quality. Total quality management (TQM) tools enable organizations to identify, investigate, and judge the qualitative and quantitative data relevant to the business.

4.3 Food Safety Management System (FSMS)

In post WTO era, food safety management systems have been well established. To assure quality and safety of agricultural produce like milk, a set of programs, viz., Good Hygiene Practices (GHP), Good Agricultural Practice (GAP), and Good Manufacturing Practices (GMP), as well as Hazard Analysis and Critical Control Point (HACCP), have come up (ICMSF 2018). At the earlier parts of the farming and milking practices, these prerequisite programs are more suitable in the dairy supply chain (Nada et al. 2012). Besides, Appropriate Level of Protection (ALOP) and Food Safety Objectives (FSO) are applied in connection to prerequisite programs and HACCP plans in a risk-based food safety management system (Gorris 2005). In industries, they have been transformed into Performance Objectives (POs), Performance Criterion (PC), Process Criteria (PrC), and Product Criteria (PdC) (Stringer 2005; ICMSF 2018). In view of public health risks associated with certain dairy products' consumption, Quantitative Microbial Risk Assessment (QMRA) has also been developed in achieving food safety for dairy products (van Asselt et al. 2017; Valeeva et al. 2005). A schematic diagram of Food Safety Management System generally adopted by a food industry is presented in Fig. 13.3. Out of several safety management systems, HACCP, ISO 22000, and FSSC 22000 are mostly adopted in dairy industry.

4.3.1 Prerequisite for Safety Management Practices in Dairy Industry

Successful implementation of safety management in a dairy industry is possible while there is a critical interdependency between safety program (such as HACCP) and prerequisite programs (PRP) (Motarjemi and Käferstein 1999). The

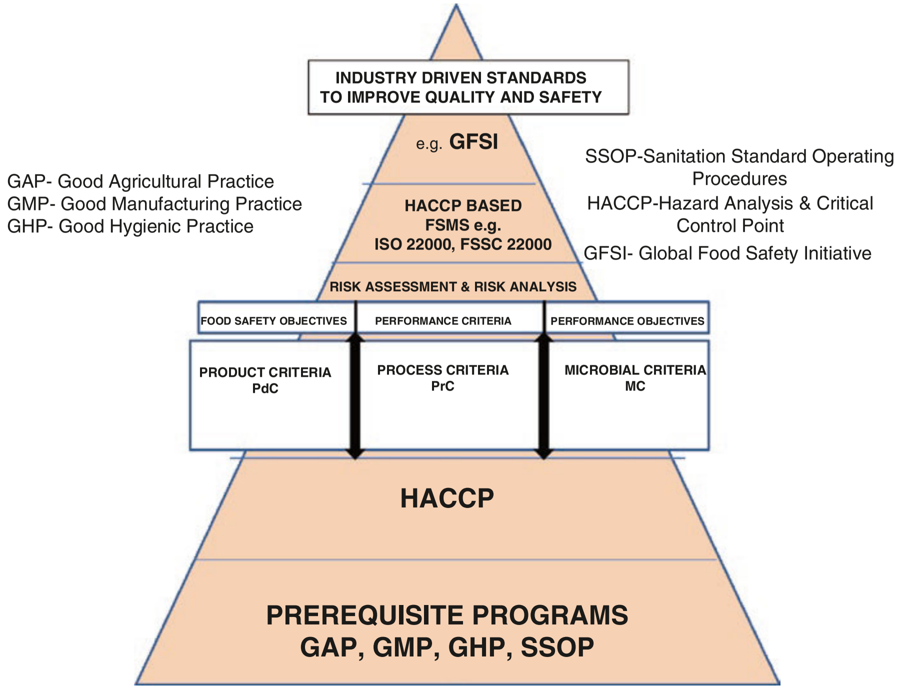

Fig. 13.3 Food safety management system

prerequisite programs (Ref: CAC/RCP01-1969 and CAC/RCP57-2004 of Codex and ISO 22002 Par 1) are:

(i) Requirements of product safety program.
(ii) Application of product safety practices.
(iii) Basic quality assurance practices.
(iv) Cleaning and sanitization of equipment.
(v) Knowledge of good manufacturing practices.
(vi) Product safety program.
(vii) Risk management program.
(viii) Pest management.
(ix) Product safety plan for a work area.
(x) Pathogen control.
(xi) Safe handling and cleaning of chemicals.
(xii) Control and prevention of foreign matter contamination.

4.3.2 HACCP (Hazard Analysis Critical Control Point)

HACCP is a preventive approach and zero risk system (Table 13.8). It provides monitoring procedures to identify the hazards, if any, and determine the critical control points in a food process. Thus, it helps to control hazards effectively in food processing plant. The implementation of HACCP involves application of seven principles (WHO 1997). Before development of HACCP plan and its execution, prerequisite programs (PRPs), as mentioned earlier, must be suitably developed, documented, and implemented. PRPs, being the foundation of HACCP, must be properly monitored and controlled for effective implementation of HACCP plan as shown in Fig. 13.4.

4.3.3 ISO 22000:2018

The International Organization for Standardization (ISO) with a Central Secretariat in Geneva of Switzerland is a global network of the national standards institutes covering 157 countries and representation of one member from each country. ISO 22000, prepared by Technical Committee ISO/TC 34, Food Products, is a food safety management system in the food chain that is involved directly or indirectly. It was first set in the year 2005. It is aligned with international standard, offering tool to implement HACCP throughout the food chain to prevent any sort of food safety hazard. The main goal of ISO 22000 is to control, reduce, or eliminate the hazard to an acceptable level. New ISO 22000 version was revised and published in July 2018. In fact every 5 years the standards are revised to determine if the revision is necessary or not, to ensure the standards are relevant to present contest and useful to business as possible. About five important key elements are there in ISO 22000: 2018 that include involvement of management team, communication, HACCP

Table 13.8 HACCP in milk products processing and storage

Products	Potential hazards	Cause	Hazard management
Raw milk	1. Biological – Contamination with vegetative pathogens 2. Chemical – (i) Contamination with therapeutic drugs (ii) presence of mycotoxins 3. Physical – Extraneous material	1. Presence of wide range of pathogens (organisms which can cause illness in humans) in unpasteurized milk 2. Contamination with aflatoxin M_1 caused by mold growth in animal feed 3. Physical objects from unclean farm environment	1. Minimization of bacterial load by collecting good quality milk and testing the incoming raw milk 2. Proper cleaning and sanitization of the milk tankers 3. Screening of drug residues as per FSSAI 2006
Raw milk storage	1. Biological – contamination and growth of vegetative pathogens in the product 2. Chemical – Cleaning and sanitizing solution residues 3. Physical – None	1. Bacterial contamination from uncleaned storage 2. Improper time-temperature condition during storage 3. Improper separation of cleaning and sanitization solutions	1. Verification of storage vessels and associated lines and valves 2. Record keeping of cleaning of storage vessels, associated lines, valves, pipeline openings (e.g., flow control panels) and outlet valves
Pasteurization	1. Biological – Contamination and growth of vegetative pathogens 2. Chemical – Cleaning and sanitizing solution residues, boiler additives, cooling water, media additives 3. Physical – None	(i) Documentation of minimum pasteurization times and temperatures to eliminate the pathogens normally present in unpasteurized milk (ii) documentation of pasteurizer regenerator sections for leak problems (iii) product contamination due to improper separation between cleaning and sanitizing solutions (iv) products contamination with toxic substances due to contact of boiler water compounds used in the production of steam	(i) Pasteurization and the design, construction, and operation and testing of pasteurization equipment must conform to all of the requirements of the grade A pasteurized milk pasteurization should be done as per applicable standard provisions (ii) maintenance of proper separation or physical break between circuits containing cleaning solution and vessels and lines. Particular attention is needed to assure that the required separation remains in place during partial washes

(continued)

Table 13.8 (continued)

Products	Potential hazards	Cause	Hazard management
Pasteurized milk and milk products storage	1. Biological – contamination and survival of vegetative pathogens 2. Chemical – Cleaning and sanitizing solution residues, boiler additives, cooling water, media additives 3. Physical – None	(i) Post-pasteurization contamination of milk and milk products due to human illness outbreak (ii) product contamination due to improper separation between cleaning and sanitizing solutions	(i) Proper protection of openings and outlet valves with fitting covers during idle time (ii) record keeping of cleaning of storage vessels after each use (iii) record keeping of the associated lines and valves and similar appurtenances for cleaning (iv) maintenance of proper storage temperature to prevent bacterial growth (v) Maintenance of proper separation or physical break between circuits containing cleaning solution and vessels and lines used to contain product

Source: Ray and Bag (2013)

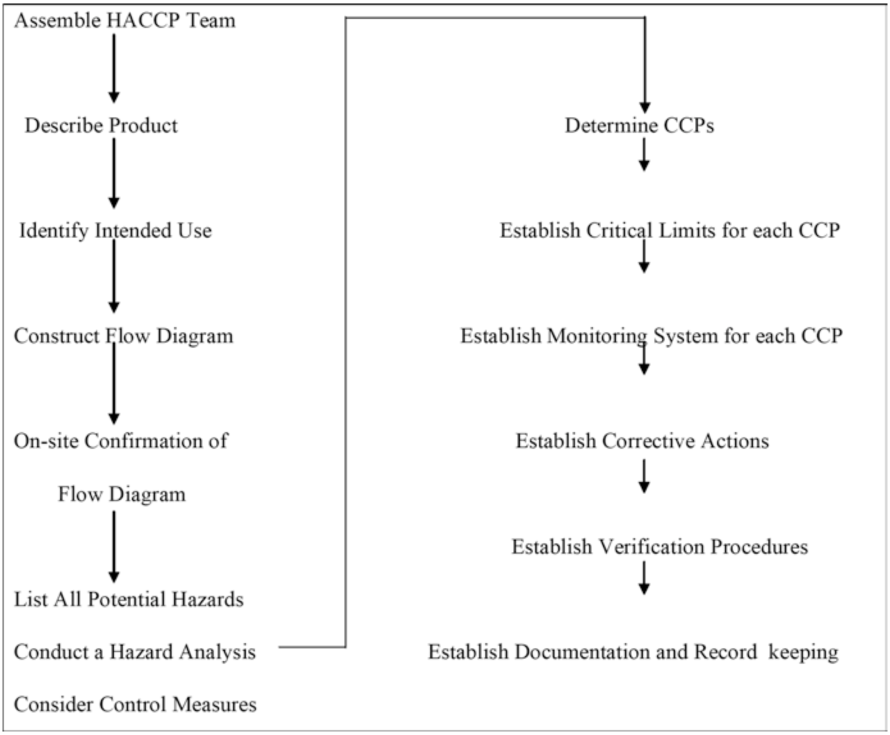

Fig. 13.4 Logic sequence for application of HACCP

principles, system management, and prerequisite program. The responsibility of food safety is not only of quality and food safety team but is the responsibility of everyone who is involved in the manufacturing process, which should be from top to bottom as well as bottom to top approach. The food safety hazard may enter at any stage of food chain. Hence, an interactive communication through downstream and upstream is very necessary. In addition internal communication throughout the food chain is very important to minimize the food safety risk and to avoid the mis-communication among food handlers. ISO 22000 recognizes the combination of HACCP and prerequisite programs (PRPs). Hazard analysis determines a strategy and PRPs set up an action plan. ISO 22000 depends on the relevant parts of ISO 9001 and integrates with the other management system like ISO 14001. The PRPs are basic conditions already adopted in the system to control the entry of food safety hazard. They are classified into two categories, i.e., infrastructure and maintenance program, that cover permanent features in food safety. The Operation PRPs are identified during hazard analysis, and they are planned to diminish the threat of food safety risk in the products' processing setting.

It is past uncertainty that the inadequacies of the ISO 22000:2005 paved way for the introduction of ISO 22000:2018. Some of the gaps that have been filled up in this new version pertain to commitment from leadership and top-level management, risk management, communication (explanation of "dynamics" of communications rather than only "mechanics"), and less rigid but more comprehensive food safety manuals. The ISO 22000: 2018 aims to shield all threats by having two distinct values employed together: one is the Plan-Do-Check-Act (PDCA) approach and another is HACCP.

4.3.4 FSSC 22000

In the year 2009, the Foundation for Food Safety Certification developed FSSC 22000 (Food Safety System Certification 22,000), an ISO-based, internationally accepted holistic certification scheme for the auditing and certification of Food Safety Management Systems (FSMS). It also offered certification for combined FSMS and Quality Management Systems (FSSC 22000-Quality). Gradually the FSSC 22000 Scheme encompassed other sectors with the target of supporting the whole supply chain. It combined ISO 22000:2005 Food Safety Management standard and the Publicly Available Specification (PAS) 220:2008 including other additional requirements. The new scheme was recognized by the Global Food Safety Initiative (GFSI), an organization committed to highlight food safety management schemes. Amalgamation of food safety management systems with other quality, environmental, and safety management systems and other GFSI-approved food safety standards enriches FSSC 22000. It fully integrates ISO 22000:2005, PAS 220:2008 Prerequisite Programs (PRPs), HACCP, and the application steps of CODEX. FSSC 22000, a comprehensive and dynamic safety program controls/reduces food safety hazards and promotes continuous improvement on food safety aspects, adopts legal compliance, upsurges transparency throughout the food supply

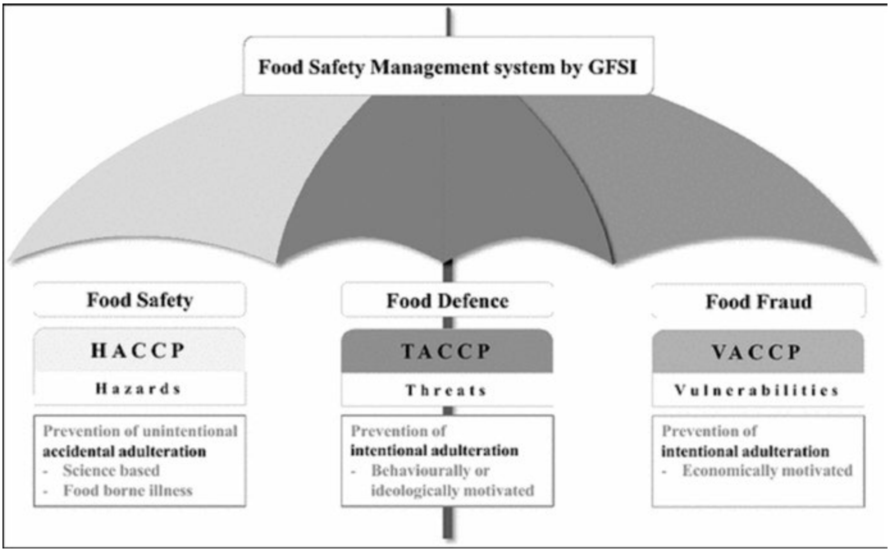

Fig. 13.5 Umbrella of food safety management system as redefined by GFSI. (Source: Bogadi et al. 2016)

chain, and enables small and/or less developed organizations to implement an externally developed system. While the concepts of HACCP consider only prevention of unintentional or accidental adulteration, prevention of intentional adulteration by ideological motivation or food threats and prevention of intentional adulteration by economical motivation or food fraud are essential requirements for holistic approach of Food Safety Management System. The GFSI has redefined the Food Safety Management considering the concepts of TACCP (Threat Analysis and Critical Control Point /Food Defense) and VACCP (Vulnerability Analysis and Critical Control Point/Food Fraud) along with HACCP (hazard/Food Safety), as shown in Fig. 13.5 (Applebaum 2014). FSSC 22000 also adopts this holistic concept of FSMS as defined by GFSI. The updated Version 5.1 of FSSC 22000 certification Scheme has been published in order to comply with the latest regulation of the GFSI and to strengthen requirements for Certification Body (CB) performance as part of continuous improvement (www.fssc22000.com).

5 Microbiological Risk Assessment in Dairy Products

Microbial risk assessment (MRA) is applied for assessing chemical and environmental contaminants. Traditionally, it consists of the following four elements (Barraj and Petersen 2004):

1. Hazard identification: The identification of the hazardous biological, chemical, and physical agents in a particular food or group of foods.
2. Hazard characterization: The qualitative or quantitative evaluation of the nature of the hazardous biological, chemical, and physical agents of food that may cause adverse health effects. For biological, chemical, or physical agents, a dose-response assessment needs to be performed.
3. Exposure assessment: The qualitative or quantitative examination of the likely ingestion of biological, chemical, and physical agents via food and contact from other sources, if any.
4. Risk characterization: This is the final step of Risk Assessment that includes quantitative analysis of hazards and exposure assessment. This is required for formulating risk management strategies.

The microbiological risk assessment (Fig. 13.6) is mainly contingent on Codex risk assessment framework and exploits the outputs of model measures that assess the risk randomly every day (FSANZ 2009). Microbiological hazards in raw milk (Table 13.9) include *Bacillus cereus*, *Brucella* spp., *Coxiella burnetii*, *Campylobacter* spp., *pathogenic E. coli*, *Salmonella* spp., *Staphylococcus aureus*, *L. monocytogenes*, *Mycobacterium bovis*, *Mycobacterium avium* subsp. *paratuberculosis*, and *Yersinia* spp. (FSANZ 2009). These organisms shed through infected animals or organisms that arrive into the milk due to poor hygiene during milking or through contaminated equipment and personnel. The risk assessment has identified four important pathogens (enterohemorrhagic *E. coli* (EHEC), *Salmonella* spp., *Campylobacter* spp., and *Listeria monocytogenes*) associated with raw cow milk that were reflected in the quantitative risk assessment model and they were selected due to their likely occurrences in raw milk, consequences in public health, and admittance to shape a quantitative model. A farmhouse model on *Campylobacter*, EHEC, and *Salmonella* revealed numerous features like with-in flock occurrence, focus on faecal origin, soiling of teat level, effectiveness in teat cleaning before milking etc. (Rhoades et al. 2009).

In the process of pasteurized milk production microbial risk may appear at every stage, when they are not monitored properly, starting from receiving of raw milk, chilling, pasteurization and final product storage. After evaluating the risks associated with the heat treatment, it could be affirmed that even the microbial hazard of greater risk, could be diminished to a satisfactory level by the adoption of GMP and GHP executed in dairy processing plants (Salgueiro et al. 2010).

6 Methods of Monitoring Quality and Safety

Various methodologies are being followed to identify, confirm, and to detect the concentration level of biochemical residues found in the milk products. These are classified as bioassay, immunochemical method, and physical-chemical assay, microbiological methods (FAO 2004).

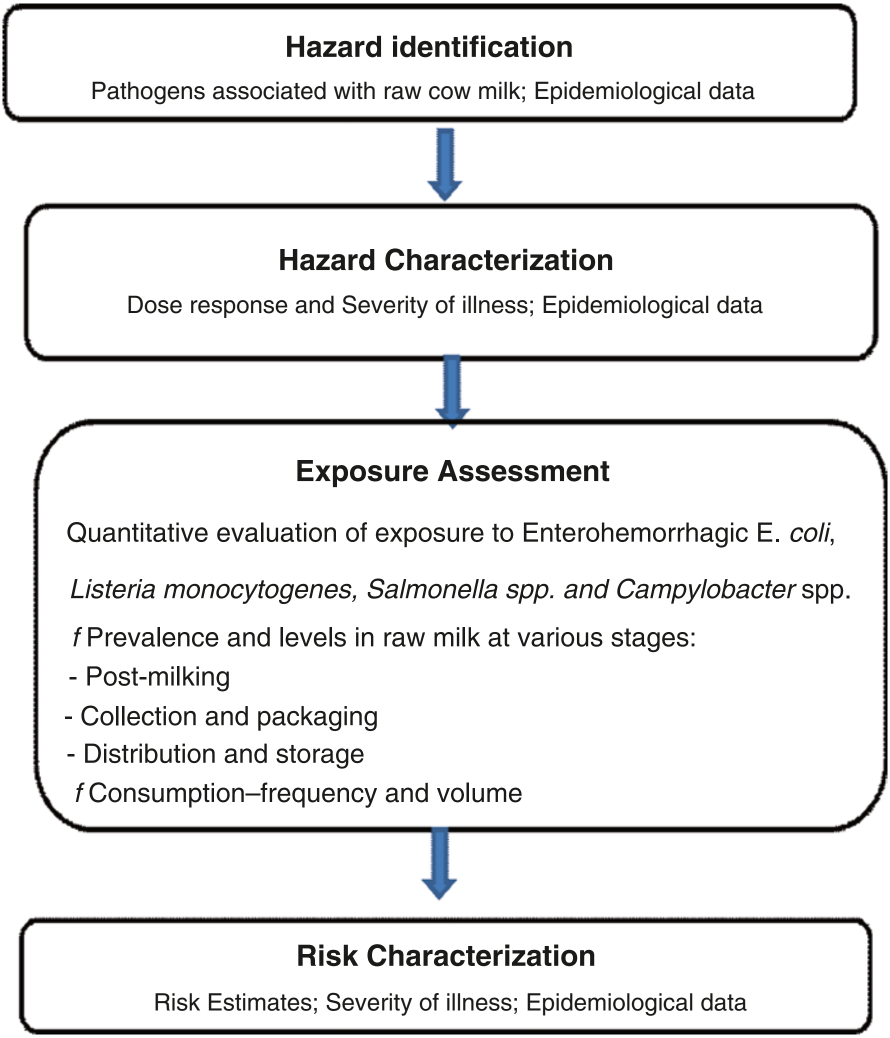

Fig. 13.6 Flow diagram of microbial risk assessment

6.1 Traditional Methods

6.1.1 Bioassay

In vivo and in vitro, these two biological methodologies are followed in bioassay procedure for determining the biochemical residues in food items (FAO 2004). The most reliable bioassay technique is performed to mice which are accepted by the regulating authorities. The toxin is injected intraperitoneally to the mice having body weight of 20 g, and their survival rate is monitored from 24 to 48 h.

Table 13.9 Microbiological hazard associated with milk and milk products due to transmission through udder affected with mastitis

Organisms	Spread openly in milk	Severity of illness	Implicated in illnesses through food
Bacillus cereus	×	Moderate	++
Campylobacter jejuni/ coli	√	Severe^	++
Clostridium perfringens	×	Severe^	+
Coxiella burnetii	√	–	+
Cryptosporidium parvum	×	Severe^	+
Enterohemorrhagic *E. coli*	√	Severe^	++
Listeria monocytogenes	√	Severe^	++
Salmonella spp.	√	Serious	++
Staphylococcus aureus	√	Moderate	++
Streptococcus spp.	√	–	+
Toxoplasma gondii	√	–	++
Yersinia enterocolitica	√	Serious	+
Cronobacter spp.[1]	×	Serious	++

Source: FSANZ (2009)

6.1.2 Immunochemical Assay

Drug residues are mainly determined significantly by immunochemical techniques. They are highly particular and lead to analytes being resolved rapidly. These measures are dependent on the response of an antigen official to a particular essential counteracting agent or for every antigen, similar to a catalyst substrate response. The most relevant immunochemical assays are radioimmunoassay (RIA), enzyme-linked immunosorbent assay (ELISA), direct and indirect competitive enzyme-linked immunosorbent assays, fluorescent immunoassay, immunoaffinity chromatography, and chemiluminescence immunoassay (María and Mary 2012).

Nowadays, modern assays and sensors are developed at cheaper and faster rate for determination of the pesticides. Enzymatic sensors, in view of the restraint of a selected catalyst, are the most popular biosensors utilized for the assurance of these compounds (Choi et al. 2001). Nowadays several specified sensors are developed for the determination of bacterial toxin and mycotoxins to control the foodborne illness (Delehanty and Ligler 2002). Optical sensor is used to trace the Aflatoxin B1 in corn which are used as a feed for the cattle. An ultrathin platinum film with an immobilized layer of antibodies, an impedance-based immunosensor, is used to detect staphylococcal enterotoxin B. Botulin with very traceable limit can be quantified with the help of evanescent wave immunosensors. *Clostridium botulinum* toxin is detected by a rapid and sensitive immunosensor. The fiber optic-based biosensor, where antibodies are covalently immobilized at the distal end, is also useful for the detection of toxin. The poison is distinguished by methods for a rhodamine mark, inside a moment at concentration as low as 5 ng/mL (Kumar et al. 1994).

6.1.3 Physical-Chemical Assay

In various samples, the dangerous biochemical residues are isolated, separated, quantified, and confirmed with the help of this physical-chemical assay.

Various chromatographic methods are used in this physical-chemical assay technique. Those are supercritical fluid chromatography, gas chromatography, affinity chromatography, high performance liquid chromatography (HPLC), size exclusion chromatography, and ionic chromatography. Several spectrophotometric methods are used singly or jointly with chromatographic methods. These are ultraviolet-visible absorption spectrometry, absorption spectrometry in the near and middle infrared sections, chemiluminescence spectrometry, X-ray fluorescence spectrometry, fluorescence, atomic absorption spectrometry, atomic emission spectrometry, nuclear magnetic resonance, inductively coupled plasma atomic emission spectrometry, mass spectrometry, and mass spectrometry in tandem (Mastovska 2011).

Mycotoxins are detected and quantified by colorimetric method, thin-layer chromatography, and high-performance thin-layer chromatography. Various pesticide residues in animal tissues are determined by gas chromatography-mass spectrometry, high-performance liquid chromatography (HPLC), gas liquid chromatography, liquid chromatography-mass spectrometry-mass photometry, etc. (Pecorelli et al. 2004). Due to its low sensitivity, colorimetric methods and thin-layer chromatography have been used limitedly. Organochlorine and organophosphorus pesticides are assessed by gas liquid chromatography and gas chromatography-mass spectrometry. Also they are effectively used to detect synthetic pyrethroid and N-methyl carbamate pesticides (Delehanty and Ligler 2002).

6.1.4 Microbiological Methods

The traditional techniques for the detection of hygiene and safety indicators in food are built on serial dilution, plating, and culturing the bacteria on Petri dishes containing specific growth medium followed by biochemical identification (Mandal et al. 2011). These are known as gold standards, and they are generally cheap and modest. However, these approaches can be time intense as they rest on the capability of the microbes to grow in diverse growth medium used for pre-enrichment, selective enrichment, selective plating, and final confirmation by biochemical tests. Normally, these techniques take 48–72 h for primary identification and more than 1 week for ratification of the pathogenic species. These techniques are protracted as they necessitate the media preparation, serial dilution, plating, and colony counting

(Mandal et al. 2011). Moreover, these methods may have limitations due to their low sensitivity. There may be false-negative results due to viable but non-culturable (VBNC) pathogens. Additionally, non-homogenous allocation and low abundance of pathogens in food, food matrix heterogeneity, and presence of natural microflora of the food matrix may interfere with the accuracy and precision of test results (Mandal et al. 2011). These techniques might also have inadequate detection potential if microorganisms are in an injured state or a VBNC state which are present in the food being tested (Foddai and Grant 2020).

6.2 Limitations in Food Examination

Microbial examination of food for both hygiene and safety indicator organisms is a challenging job for almost all techniques. The problems may be due to the following factors:

(a) Non-uniform distribution of bacteria in food.
(b) Food matrix heterogeneity.
(c) Interference of food components such lipid, proteins, sugars, preservatives, etc.
(d) Type of food based on physical form (dried foods, liquid, semi-solid, or other forms).
(e) Consistency of food like lipids and oils that may interfere in mixing.

6.3 Requirement for Fast Technique

The operational evaluation of microbes needs techniques that can achieve various counts of features that are challenging. The detection conditions, i.e., time and limit of detection, are the very important drawbacks associated with the expediency of any microbiological analysis techniques. Presently, the need of the hour for food industries is use of rapid methods that are very much thoughtful for the succeeding reasons:

(a) To deliver instant evidence on the likely incidence of bacterial pathogens in raw material and final products.
(b) Small number of pathogens are habitually existed in competitive microflora already present in food matrix.
(c) Only 1 cfu pathogenic bacteria in food can be critical for causing infection.
(d) For observing process control, cleaning, and sanitation activities during processing.
(e) To eliminate humanoid errors and to protect wastage of time and labor charges.

6.4 Rapid Techniques

Various new rapid techniques with lower limit of detection and higher selectivity have been advanced to overtake the challenges of culture-based techniques for the evaluation and detection of bacterial pathogens that are associated with foodborne illnesses. Besides, various investigators are involved in the development of novel methods with enhanced detection time, selectivity, sensitivity, and appropriateness for in situ evaluation and appropriateness for in situ analysis and differences among viable cell (Valderrama et al. 2016). They are adequate with respect to sensitivity to detect foodborne pathogens that present in low numbers (Mandal et al. 2011). However, each of these techniques has their own advantages and limitations. Mostly, these techniques are usually grouped into three types: immunological, nucleic acid-based assays, and biosensors (Goodridge et al. 2011). Most of these techniques can evaluate a sample in few minutes to a few hours, but still there is a dearth of appropriate LOD and selectivity for the detection methods of food (Feng 1997).

6.4.1 Immunology-Based Methods

There is an extensive practice of immunological-based techniques in the food industry due to their lower limit of detection, mechanization, and high selectivity (Valderrama et al. 2016). The selective binding of antibodies to their specific antigen, rapid and easiness of this interface have explored the progress of an extensive variation of assays based on immuno-chemistry (Feng 1997). The antibody-antigen bindings are applied broadly in the detection of pathogens immunologically. Enzyme immunoassay (EIA) (Chapman et al. 1997), enzyme-linked immunosorbent assay (ELISA), enzyme-linked fluorescent assay (ELFA) (De Giusti et al. 2011), flow injection immunoassay, and other immunological methods are ordinarily used for immunological detection (Shukla et al. 2018). They need a shorter period to make the test than in culture-based methods. But, real-time pathogen recognition is not possible by these types of methods.

In food industry, various commercially available immunological-based techniques are used for the detection of bacterial pathogens. For examples, VITEK Immuno-Diagnostic Assay System (VIDAS) is a high-throughput and automated version of the ELISA assay, which allows a more sensitive fluorescence-based detection (Ferone et al. 2020). The VIDAS® assay (bio-Mérieux) magnificently aims a steady virulence antigen in an *L. monocytogenes* specific, ELFA (Janzten et al. 2006). VIDAS is actually a qualitative assay; however the higher the mass of the antigen, the greater the amount of the captured fluorescence. In an intra-laboratory study involving many labs in the region, VIDAS® LMO II immunoassay was evaluated (Janzten et al. 2006). VIDAS can be used in rapid detection of various bacterial pathogens like *L. monocytogenes*, *Salmonella* species, *E. coli* O157:H7, and *Campylobacter* species in a variety of food matrices (Meyer et al. 2011). The system can generate the results of an assay within 45–120 h, depending on the test kit. But, this immunological method may have a potential demerit due to possible interference with toxins present on foodstuffs, and thus, it is not appropriate for real-time detection of microbial spoilage in foodstuffs (Ferone et al. 2020).

6.4.2 Molecular-Based Methods

These methods are run by sensing precise RNA or DNA sequences of the target pathogen. Polymerase chain reaction (PCR) is the utmost frequently aid in nucleic acid amplification technique for bacterial pathogen detection, and over the last two decades, numerous dissimilar progresses on the ground-breaking PCR procedure have been explained by Priyanka and co-workers (2016). Even though they are being known as rapid, specific, and sensitive methods, these will not give any idea on the viability of dead cells, as they are not able to distinguish between live and dead cells. To overcome this constraint, the cell viability dyes may be used in amalgamation with DNA amplification approaches (Pan and Breidt Jr. 2007). There are many molecular-based techniques including hybridization-based methods, viz., fluorescent in situ hybridization (FISH); amplification methods, PCR, qPCR, and RT-PCR; DNA microarrays; and whole genome sequencing-based techniques (Fenollar and Raoult 2004; Hasman et al. 2014). These techniques comprise of assured genomic markers that resemble to selective nucleic acid sequence and known to be non-culture-dependent techniques (Broekaert et al. 2011). Some examples of different applicable molecular-based methods for the detection of foodborne pathogens have been reported in Table 13.10.

6.4.3 Biosensors

A biosensor is a kind of transducer device that can detect physical activities as well as chemicals present in living organisms (Alahi and Mukhopadhyay 2017). Thakur and Ragavan (2013) described the prerequisites for developing a biosensor system. Different bio-receptors are available for their use in biosensors to amplify the efficiency of measurement by the biosensors.

Types of Biosensors

The classification of biosensors is given in Table 13.11.

Application of Biosensors

Electrochemical biosensors quantify the changes in electron transfer using a suitable electrode during an oxidation/reduction reaction (Rasooly and Herold 2006). Among these types, an amperometric biosensor can detect the modifications in

Table 13.10 Molecular-based techniques for detection of foodborne bacterial pathogens

Techniques	Merits	Demerits	Name of the bacteria	Name of the food	Limit of detection	References
Classical PCR	Automated reliability with high sensitivity and high specificity	Requires DNA purification step and no distinction between viable and non-viable cells	*Pseudomonas* spp, *Serratia marcescens*, *Hafnia alvei*, *and Citrobacter freundii*	Raw cow's milk	10^3–10^5 CFU mL^{-1}	Ercolini et al. (2009)
Multiplex PCR	Automated reliability with high sensitivity and high specificity and detection of multiple species	Requires DNA purification step, no distinction between viable and non-viable cells and designing of complex primers	*Cronobacter sakazakii*	Commercial infant food formula	1.6×10^1 CFU/mL	Aksu et al. (2018)
			Listeria monocytogenes, *Staphylococcus aureus*, and *salmonella* spp.	Raw milk	10 CFU 25 g^{-1}	Wei et al. (2019)
			Pseudomonas species	Raw milk	10^{-3} CFU. g^{-1}	Maier et al. (2021)
Real-time PCR	Automated reliability with high sensitivity and high specificity and no purification of DNA products	High costs, no distinction between viable and non-viable cells and chance of cross contamination	*Listeria monocytogenes*, *salmonella* spp., *S. aureus* and *Shigella* spp.	Dairy products	5 CFU 25 g^{-1}	Ruiz-Rueda et al. (2011), Ma et al. (2014)

Table 13.11 Classification of biosensors

A. Signal transduction	
Electrochemical	Conductometric, Amperometric, Potentiometric, Impedimetric
Optical	Absorption, reflectance, Raman scattering, fluorescence/phosphorescence, bio-chemiluminescence, refractive index, surface plasmon/total internal reflection, diffraction, polarization
Mass sensitive	Surface acoustic wave biosensors, piezoelectric biosensors, cantilever biosensors
Thermometric	Calorimetric biosensors
B. Recognition molecule	
Antibodies	Monoclonal, polyclonal
Lectin	Carbohydrate binding proteins
Enzyme	Catalytic types and inhibition types
Protein receptors	Ionotropic receptors, metatropic receptors
Whole cell	Microbial sensors, mammalian cells, tissues
Nucleic acids	Hybridization, low weight compound interaction
Spores	Bacterial endospores – Inhibition type, germination types

current by gathering of concentrated electro-active species, e.g. electrolyte gas sensors, electronic noses. Amperometric biosensor for *E. coli* O157:H7 has been developed with the wide range of detection limit ranging from 107 to 101 cells/mL having significantly low limit of detection i.e. 1 cell/ml (Dhull et al., 2019). In case of potentiometric biosensor, it depends on changes in potential of a system at constant current (I = 0) or detects the change in distribution of charge, e.g., ion-selective electrodes (such as pH meter), ion-selective field effect transistors, and LAPS. In milk, the detection of *E. coli* CECT 675, a nonpathogenic counterpart for *E. coli* O157:H7, a real-time aptamer-based potentiometric biosensor was used (Wang and Salazar, 2016). Recognition of *E. coli* with LOD of 7.1×10^2 cells/ml in 30 min with an 18–24 h pre-enrichment in selective media has been developed. Conductometric biosensor measures the variation in conductance of the biological complex placed between electrodes. Or it involves the measurement of modifications in conductance due to the movement of ions. Many enzyme-linked responses result in a change in total ion concentration. A conductometric immunosensor for the detection of *E. coli* O157:H7 based on electrochemical sandwich assay with the detection limit of about 7.9×10^1 cells.ml^{-1} in pure culture within 10 min has been developed (Tokarskyy and Marshall 2008).

Piezoelectric biosensor based on change in frequency captures changes in mass, density, viscosity, and acoustic coupling phenomena, e.g., surface acoustic wave sensors. QCM immunosensor detects *E. coli* 0157 within 4 h based on beacon immunomagnetic nanoparticles with detection limit of 23 CFU/ml in PBS and 53 CFU/ml in milk. It requires 24 h pre-enrichment at 37° C (Law et al. 2015).

Optical biosensors involve optical transducers where a biological material (e.g., ligands, functional proteins, or antibodies) or a biological system (e.g., living cells, bacteria, or tissues) is placed in contact with the surface of a biosensor to form a biological layer (Fang et al. 2006). The interaction between a target analyte and the biological layer produces a change in optical contents of the reflected light that is detected by the transducer (van der Greef et al. 2004). Generally, there are two types of detection protocols in optical bio-sensing: fluorescence-based detection and label-free detection.

7 Conclusions

The consumers expect that milk and milk products will always be safe and meet the quality standards. Despite noticeable advancement in technology, the availability of safe milk and milk products is still a challenge worldwide. Remarkable change in consumers' demand of food leads into innovation and new regime of product development. Increasing popularity of ready-to-eat dairy foods may proliferate the chances of microbial contamination. Enhanced awareness of nutrition and wellness trigger demand of farm fresh, organic, shelf-stable products. Inadequate knowledge and skill for processing and preservation of such products may jeopardize the ultimate goal. The impact of globalization is also visible in changing pattern of food consumption that encourages more of import-export business in milk food industry. Consequent adoption of globalized food supply chain through geographically dispersed route adds on the challenge for catering safe and nutritious food. Emerging trend e-commerce also influences the food sector including dairy sector. This trend intensifies food safety challenges due to inconvenience in temperature control and its monitoring during shipment, identification of traders, sampling, etc. Climate change and its impact on dairy chain also increase difficulty for maintaining safety and quality of milk and milk products at every step of the chain. Another important aspect includes advancement in innovative and intelligent dairy food packaging for delivery of safe and wholesome dairy products in cost-effective mode. Considering different drivers of variations, adoption of effective risk assessment and risk mitigation approach is the need of the hour. For the purpose of advanced molecular mechanisms, principles of predictive microbiology and application of software-based surveillance and detection and methods overall management are widely used in leading dairy food industries. Due to the increasing complexity of dairy food chain management, regular updating of food safety and quality management system involving real-time communication within the milk chain, management review, internal audit, evaluation of individual verification results, and corrective actions and feedback are the key areas for achieving the best public health outcome in terms of microbiological and chemical quality and safety of milk and milk products.

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Part V
Fisheries and Aquaculture in Food Security and Nutrition

Chapter 14
Diversification in Aquaculture Resources and Practices for Smallholder Farmers

S. K. Das and Amit Mandal

Abstract Rural aquaculture and peri-urban aquaculture have been recognized as significant contributors in the economy of the developing world. Smallholding rural aquaculture has been conceptualized as the farming of aquatic organisms by small-scale farming households and communities through extensive or semi-intensive production system utilizing low cost resource as inputs. Small-scale aquaculture contributes in the societal development in the rural and semi-urban economy involving over 41 million folks worldwide. The operational attributes of smallholder aqua-farming is centered round three principal components like culture species, inputs, and capital. In contrast to European finfish aquaculture dominated by only two species, rainbow trout, *Oncorhynchus mykiss*, and common carp, *Cyprinus carpio*, culturable species of finfish are significantly diverse in Asian countries. Though major carps are considered as the pillars of small-scale production, exotic carps and indigenous minor carps are contributing significantly. The objective focus of the smallholding aquaculture practitioners particularly in the developing Asian countries aims at more heterogeneity in species of culture based primarily on the localized niche market demand that could be supported with low cost cereal and pulse processing wastes and animal husbandry by-products as basic inputs. Parallel with diversification needs, there is a growing interest on introducing different cat fish, murrels, pangasius, tilapias, gourami, ornamental fish, and minor carps, and even previously considered "weed and unwanted fish" turned out as a most valuable fish in the small-scale aquaculture sector. Intensification rather up-scaling through diversification of resources in smallholding aquaculture depends on four principal attributes, viz., (i) resource utilization, (ii) capital, (iii) culture environment, and (iv) species of culture. As production process largely depends on local environmental conditions, it is impractical to have common technology or practice extended to all

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_14

locations towards diversification in resource use in small-scale aquafarming. The need and goal of diversification in small-scale aquafarming is primarily centric towards economy where ecological attributes are seldom being focused particularly in the Asian countries. The present article discusses the attributes, constraints, and suggestive measures in the inclusive diversification of smallholding aquaculture.

Keywords Small scale · Aquaculture · Diversification · Constraints · Diversification strategies

1 Introduction

Globally, an estimated aquaculture production enhancement by at least 50% by 2020 is necessary that can be achieved through technological interventions within the blue revolution framework (FAO 2021). As most of the capture fisheries resources are considered either as fully exploited or overexploited, aquaculture will continue to play a crucial role in meeting fish demand of the growing population and market (Kawarazuka and Bene 2010). Asia is considered as the epicenter of aquaculture activity where traditional practices are centered largely around small-scale operations, often farmer-owned and managed, and more so clustered in an area that is conducive to aquaculture. Aquaculture practices are integrated with other primary production practices, particularly in Asia. Asian countries contribute over 85% of aquaculture production in the world mostly through the small-scale aquaculture gateway (De Silva and Davy 2010). There was agreement that aquaculture, particularly small-scale aquaculture, has always been about people and rural communities (Umesh 2007). Village level rural aquaculture and peri-urban aquaculture have emerged out as significant contributors in economy in the developing world. Globally, rural aquaculture sector is considered as the untapped niche area of production and coined as small-scale aquaculture (SSA) with diverse spectra. It is related with small-scale farmers having small land holdings in and around the farming households with minimum technological interventions. Small-scale rural aquaculture has been defined as the farming of aquatic organisms by small-scale farming households and communities through extensive or semi-intensive low cost production system based on the utilization of appropriate resource (Pillay 1997). However, in reality, “aquatic organisms” under smallholding farming refer to a limited number of finfish and shell fishes in most cases, whereas “appropriate resources” are centered around low cost agricultural and animal husbandry wastes.

Small-scale aquaculture continued to contribute in the societal development process in the rural and semi-urban economy involving over 41 million folks worldwide. The overwhelming majority of the smallholding farm families live in developing countries, operating in fish production, providing food security and nutrition, ensuring fresh fish in and around the vast unorganized rural market which often remained unnoticed or under documented. Finegold (2009) observed that small-scale farmers are key operators supplying the most affordable variety of animal protein as fish to the poor. Small-scale aquaculture has direct and indirect benefits to the livelihoods of the rural poor farming community. The direct benefits include high-quality food, self-employment opportunity even of the women folks, and fetching income through sale of high-value farm-fresh produce. The indirect benefits include secured availability of low-valued fish in local market, co-lateral employment generation in farming and marketing, network for seed supply and market chain, and in ensuring culture sustainability safeguarding the ecology of the culture environment. Besides, it enhances the decision-making capacity, societal status, and leadership capacity of the farmers as well.

2 Characteristics of Small-Scale Aquaculture

The characteristics of small-scale aquaculture are mostly targeted to the development of rural economic status and livelihood generation. The characteristics of such farming include overall dependency on households (Friend and Funge-Smith 2002), subsistence activities (Prein 2002), aquaculture and agriculture diversification (Prein 2002), ownership of whole family (De Silva and Davy 2010), and access to small resources (Bondad-Reantaso and Prein 2010). However, the most discernible characteristic inherent within is the complementarity and amalgamation of different sub-systems of farming and husbandry practices both vertically and horizontally which have eventually strengthened each other towards long-term economic sustainability. Such auto-integrated system of resource sharing and utilization under a closed loop practice becomes a signature mark of small-scale aquafarming in rural and peri-urban economy of the poor masses. The strength, opportunity, weakness, and threat (SWOT) perceptions of small-scale aquaculture are presented in Fig. 14.1.

3 Attributes of Small-Scale Aquaculture

The SSA system, in general, has been categorized under type I and type II (Edwards 2013). Type I system known as the “poorest of the poor” aquaculture involves limited investment in the assets, operational cost, and large family labors with very low output. The small-scale farmers efficiently utilize the available resources to fulfill their own consumption demand and also possess the liberty to sell the extra produce in local level market to earn money. Type II system known as “less poor” aquaculture is based on livelihood generation through aquaculture which is solely dependent on limited resources, infrastructure with low to medium investment, and output. The farmers have marginal land holding capacity for production with integration with agriculture activities. The small portion of output is consumed, and the rest of the portion is sold in markets for generating income. Small-scale rural aquaculture does not have any additional pressure on local resources or contravene on the nutrition or livelihood (Yap 1999). Bondad-Reantaso et al. (2009) have documented

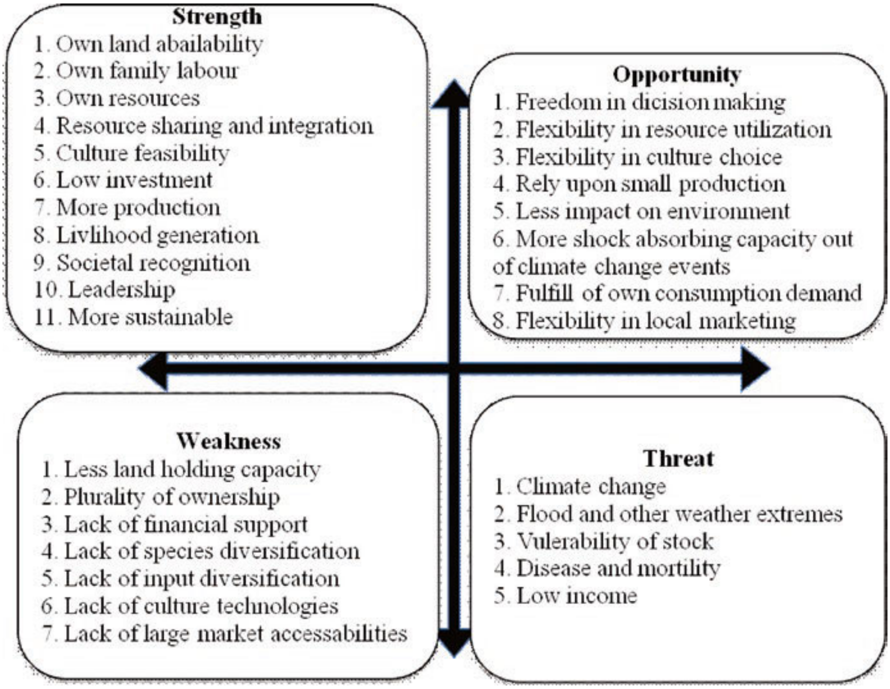

Fig. 14.1 Strength, opportunity, weakness and threat (SWOT) perceptions of small scale aquaculture

several attributes of SSA. The attributes encompassed under type I are family labors, informal management structure, a certain degree of vulnerability, limited resource and technical feasibility, and limited access to market information. The type II includes low investment, less sell of produce, and low income.

The operational attributes of smallholder aquafarming revolve round three principal components like culture species, resource (input), and capital (Fig. 14.2). Towards intensification of operation through diversification of resources, viz., land, water, and species of culture; inputs, viz., feed and manure; and capital, probable interactive attributes are presented in Fig. 14.3.

The multi-directional use of village ponds, poor management, and lack of species diversification are considered as the major barriers for increasing fish production. In contrast to European finfish aquaculture which is largely dominated by two species, viz., rainbow trout, *Oncorhynchus mykiss*, and common carp, *Cyprinus carpio* (FEAP 2012), culturable species of finfish are diverse in Asian countries. Though small-scale farmers presently rely upon production of major carps, exotic carps, and certain extent of minor carps, there is a growing interest and scope of introducing different cat fish, murrels, pangasius, tilapias, gourami, ornamental fish, minor carps, and even previously considered “weed and unwanted fish” (Table 14.1).

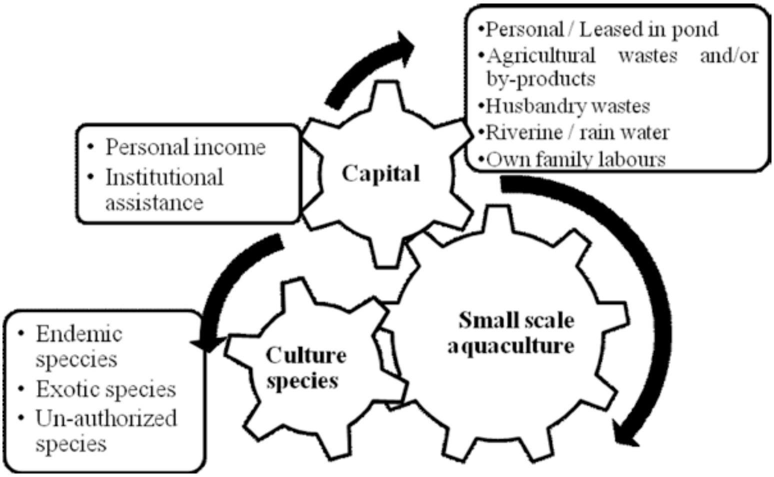

Fig. 14.2 Operational attributes of SSA

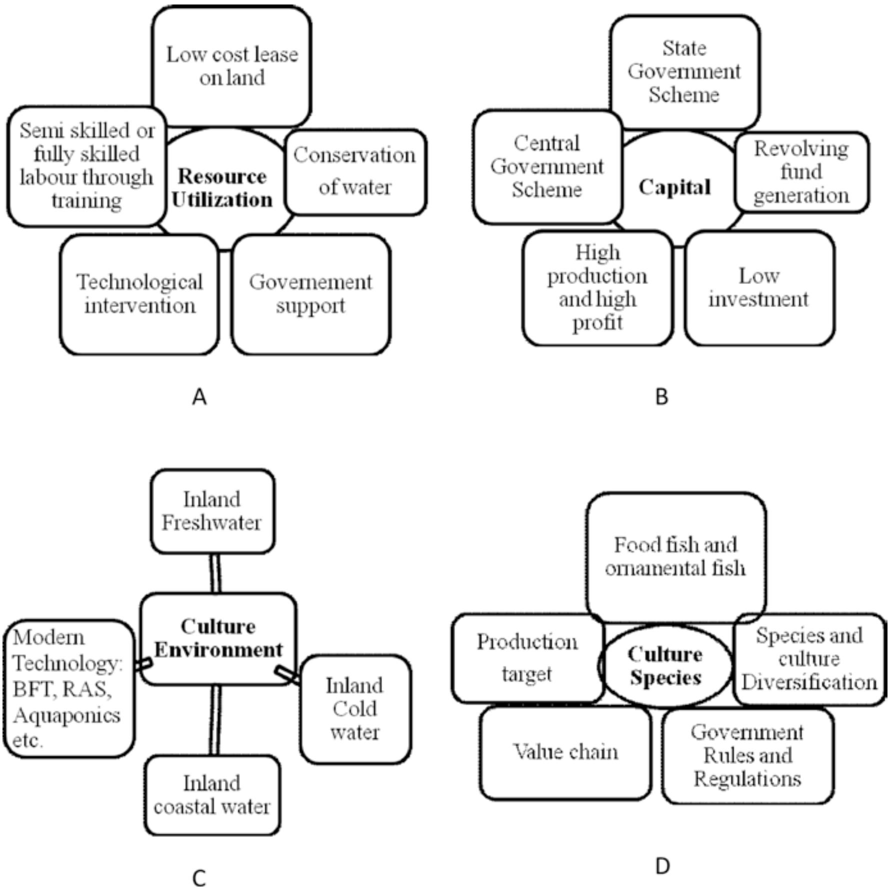

Fig. 14.3 Intensification through diversification of resources (**a**) Resource utilization, (**b**) Capital, (**c**) Culture environment and (**d**) Species of culture

Table 14.1 Layout of different attributes in small-scale aquaculture

Finfish / shellfish and ornamental fish

Indian major carps, exotic carps, Asian catfish, stinging catfish, butter catfish, knife fish, trout, mahseer, freshwater prawn, tiger prawn, white leg shrimp, mussel, oyster, clam, freshwater ornamental fish

Species diversification

Approved new species: GIFT tilapia, Amur carp, Sutchi catfish

Illegal entry: African catfish, Vietnam koi

Culture diversification

Modified extensive to semi-intensive, Polyculture to composite culture, Integrated aquaculture, Tank based monoculture, Intensive culture in tank like biofloc, RAS, raceway

Government Rules and Regulations

Trans-boundary entry, Strict guidelines, Quarantine facilities, Approved standardized technologies for fish breeding

Value chain

Network of fish farmers, Aquaculture field school, community based resources management, FFDA, BFDA, SHG, Supporting authorities like ICAR, MPEDA, NFDB, CAA

Production target

Blue revolution, Sustainable approach, Equity in utilization of resources, Eco-friendly technology, climate resilient culture system, introduction of new species

In many parts of Asia, small-scale, low input aquaculture technologies are seen as an important tool for improving food security, especially in areas where there is a shortage of fresh fish (Das 2006). Most of the farmers engaged in this sector are traditionally trained and experienced through the years of practice. The financial input comes only from their own resources and at times from the government schemes and subsidies on construction of pond and purchase of input materials. Regarding feeding their stock, the system runs primarily with “feed the pond to feed the fish” concept where most of the farmers prepare low cost mash by using rice bran and oil cake. Nowadays, government of many Asian countries including India has taken several initiatives to train the farmers to enhance the fish production through efficient utilization of resources alongside with emphasis on integrated farming approach. Rice-fish farming is a small-scale aquaculture activity that is commonly integrated with other farming operations. The income of 2–3 million households in China have significantly increased through rice fish farming, with income two to four times that of sole crop farming (De Silva and Davy 2009).

Besides these, the focus of small-scale aquaculture should lay on the different approaches through horizontal and vertical diversification, proper following the rules, regulations, and guidelines set up by government and other organizations to achieve the maximum production in sustainable way (Table 14.1).

4 Prospecting of SSA

The present scenario of small-scale aquaculture is based on the traditional culture system of commercially important fish and shrimp species, and the culture system is mainly modified extensive type in India. Only a few species, viz., Amur carp and GIFT tilapia, have been approved by the Government of India, and farmers have started culture through both mono species culture and composite culture systems. Besides this, several prospective of small-scale aquaculture can be achieved through the adoption of sustainable livelihood approach (SLA) where the orientation and management of small-scale rural aquaculture is considered as the potential means for enhancement of rural economy, mitigation of food security, and livelihood generation. Also, through SLA, aquafarmers are encouraged to enhance the productivity by (i) raising carrying capacity of the pond, (ii) more involvement of family members in farming, (iii) improvement in resource utilization, (iv) integration approach through the possible combination of the different components in the fish farming, (v) optimally utilizing farm areas, (vi) recycling and reuse of farm wastes to enhance the farm income for the family livelihood and better sustainability.

Aquaculture field school (AFS) is another approach to integrate fish farmers to enhance fish production and income generation by improving decision-making capacity among farmers in small-scale aquaculture. Different possibilities like brood stock management, nursery and feed management, disease diagnosis, feed formulation, integrated farming, soil and water analysis, and technology on culture practices can be fulfilled through AFS.

Utilization of resources through community-based management can be the best possible way to utilize common property resource like village ponds. Besides all these, small-scale aquafarmers are the flag bearers in inventing, refining, and applying a number of indigenous technical knowledges of which some might be traditional at different facets of their farm management (Table 14.1) which has seldom been well documented and recognized. There is enough scope of more and more adoption of such indigenous merits, materials, and techniques based on the local perspectives in the intensification process through diversification in SSA.

5 Need and Goal of Diversification

The word "need" is highly non-elastic and very often overshadowed by "want" as the thin boundary line in between becomes obscured by consumerism in the rapidly changing globe. Though "need" has been defined diversely by the social scientists, economists, and politicians with different perspectives (Harris and Lorenzo 2000), however, the word "need" bears an inherent compulsion in achieving or having something not only for meeting the gaps of basic requirements for mere survival but also for maintaining the continuity in the process of socio-economic uplifting and dynamic issues of sustainability of individual and the society as a whole. In the farm-based production sector, the horizon of the word need is further extended being inclusive of consumers' need besides individual necessity, simultaneously taking care of the ecological bearings and rationalization in resource use.

The concept of diversification in aquaculture, in general, has been emphasized in terms of (a) species, (b) technologies, (3) geography and environment, (4) markets, and (5) governance (Harvey et al. 2017). However, the objective focus of the smallholding aquaculture practitioners particularly in the developing Asian countries aims at more heterogeneity in species based primarily on the localized niche market demand that could be supported with low cost cereal and pulse processing wastes and animal husbandry by-products as basic inputs. Also, technology herein is based on diversification with low cost locally available inputs as nutrients as the pond-based production system operates with the principle of "feeding the pond to feed the fish." This is in sharp contrast to the application of high cost feed with high stocking density type of intensification approaches. Therefore, to the smallholding farmers diversification in heterogeneous resource usage is more important than intensification in the management process with a few high value carnivorous fish supported with high-value feeds.

During the recent years, local market economy has become stronger commensurate with the economy's increasing purchasing capacity of a sizable population in the rural and peri-urban populations. Also, understanding on the nutritional aspects of different fish and fishery by-products has also been increased dramatically. The consumers including the farmers become more conscious towards the nutritional value and quality of different finfish and shellfish. Such enhanced understanding and economic strength have resulted in more choice and purchasing options of the consumers even among the non-urban populations. Therefore, the localized market has acquired the capacity to support a wide range of aquaculture produce barring a few species used to handle in the earlier days.

To most of the small-scale fish farmers, aquaculture along with household animal served as secondary sources of livelihood; intensification by means of diversification in terms of species, low-cost resource use, and cropping pattern has become more pertinent. This is because of increasing risk and profit marginalization in the agriculture sector being their primary source of income. Crop failure, lack of minimum support price, increasing cost of production, market uncertainty, and climate change-related factors led the marginal farmers further marginalized in the agriculture sector. In contrast, market constraints are seldom faced by the small-scale fish farmers as they never rely on far away organized marketing system; rather nearby local markets have become even stronger so far fish as a commodity is concerned.

Besides, fish being the cold-blooded animal is better adjusted with the climate change-related extremes particularly in the inland aquaculture sector in the tropical and sub-tropical regions of the globe. Therefore, the small-scale aquafarmer is more buffered in the event of any setback with his primary livelihood from agriculture if diversification in aquaculture practice with affordable low cost locally available of resource use is adopted. Several studies (Le François et al. 2010; Harvey et al. 2017) have argued that species diversification could lend the sector resilience, particularly under climate change.

Diversification in the small-scale aquaculture sector is needed to (a) enhance livelihood and income of the farmer, (b) generate employment, (c) reduce gender bias, (d) meet the changing demand primarily of the local consumers, (e) conserve indigenous small fishes which have been dramatically transformed from "unwanted, uneconomic" to mostly demanded high-value fish of low trophic level, (f) achieve heterogeneity in species option towards increasing sustainability, (g) decrease risk of farming a few conventional species only, (h) achieve more complementarity among different species under variable agri-husbandry by-products as low-cost inputs, and (i) achieve economic stability by increasing capacity to absorb shock out of sudden price variability of a particular or few species. Therefore, the need for diversification to the small-scale aquafarming community is primarily economic where ecological avenues are seldom being focused particularly in the Asian countries where they serve as the backbone in serving the baseline local market with fresh products.

The multifunctional approach in small-scale aquaculture requires different activities to enhance production and livelihood generation like nutrition for consumers (NFC), aqua-tourism system (ATS), aqua-market system (AMS), etc. The need of diversification requires for articulating a farmer's strategy to establish farming activities together with the combination of other activities in continuation with his prime objectives.

Though the holdings and operational intensity is seemingly small, the goals of diversification in smallholding aquaculture are diverse. Though the primary goal is individualistic, concerning with the farmers in terms of economics, the ultimate goal is to attain self-reliance with diminishing dependency to the other components of the society. This is not only for survival and sustenance as delineated in "need," but in a broader perspective, it will enhance the economic capacity to suit in more diverse conditions. From individual farmer level, the goal diversification will encompass the whole sector strengthening sustainability with increased heterogeneity in the culture spectrum though in a small scale. As this system forms the backbone of inland aquaculture comprising both freshwater and brackish water culture habitat in Asian and African continents, strengthening this sector through diversification will ensure more resilience and sustainability. The goal of diversification in small-scale aquaculture is various which can match the expected outcomes through multispectral and multifunctional possibilities like (i) the durability of farm business through creating the additional value, employment, and complementary incomes; (ii) promotion of culture effectiveness through adoption of new technologies and culture suitability of new species in varied agro-climatic conditions of the country; (iii) achievement of higher production through sustainable development, and (iv) development of new alternative to expand the aquaculture farm facilities in rural areas.

The sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations (Lutteken and Hagedorn 1999). Diversification can be possible through maintaining sustainable production environment, new strategies like cluster farming, integrated farming, and also new market strategies. Diversification in small-scale aquaculture should be developed through effective utilization of farm resources in which the new creation of investment alternatives can be possible in both culture and small-scale industries (Schmidt et al. 2011). Therefore, the diversification will be relying upon the sustainable development through the different considerations (Fig. 14.4).

6 Attributes in Diversification

The diversification attributes should be important with respect to the farmers' economic capacity. Aquaculture diversification is a tool for sustainable approach against climate change to reduce drudgery and support to poor and marginalized communities by promoting market opportunities of aquaculture products. The diversification provides option associated with demand, knowledge gaps, market, business opportunities, and climate change for using suitable finfish and shellfish species in aquaculture systems (Gurung et al. 2018). Through diversification in SSA, it is possible to ensure supply of heterogeneous species at different seasons with affordable price primarily to the local level consumers. Therefore, it can enhance the spectrum of choice of commodity of the base level consumers. The diversification may be possible at different levels of both in very small holding farmers (Fig. 14.5) to small-medium holding aquaculture system (Fig. 14.6).

Fig. 14.4 Sustainable diversification approach of SSA

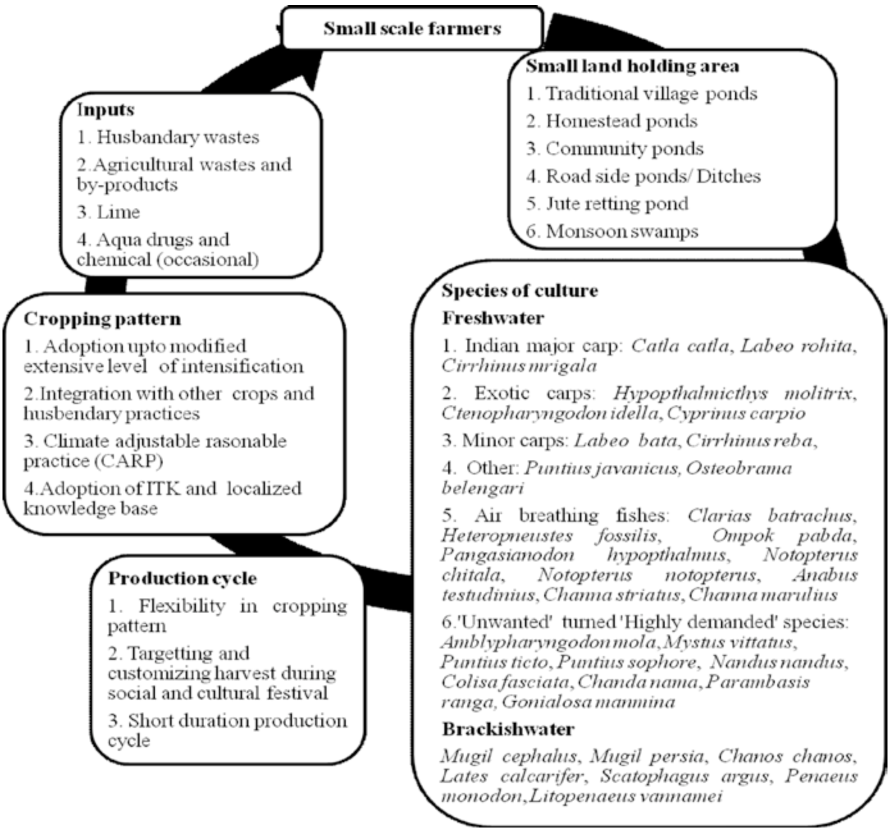

Fig. 14.5 Attributes of SSA for small-scale farmers

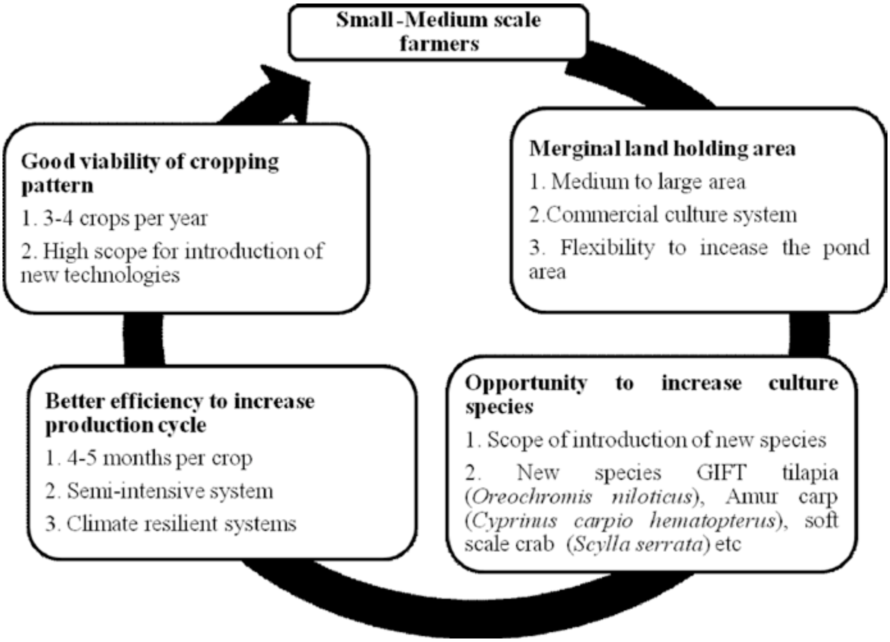

Fig. 14.6 Attributes of SSA for small-medium-scale farmers

7 Diversification Pathways

Diversification may be possible at different levels in small-scale aquaculture system in different pathways either in single or in combinations:

(i) **Diversification in Culture Site**

South and South-East Asian countries are considered as one of the most suitable geographical zones for small-scale freshwater rural aquaculture development due to their favorable resources and agro-climatic conditions. Small-scale inland aquaculture in this zone has the greatest potential because aquaculture can be functionally integrated with the existing agricultural and husbandry practices. Homestead ponds are used for multiple purposes including bathing, washing, and watering livestocks besides culturing fish and thereby naturally integrated. Aquaculture activities might be diversified beyond such boundaries of traditional water bodies where with effective strategies, appropriate cropping pattern with appropriate species and culture duration will be adopted. Such diversification will not only be centered around aquaculture but also will entail efficient utilization of land and water resources. Most of the farmers engaged in small-scale aquaculture activities rely upon small-holding household ponds or ponds with pluralistic ownership from their own locality. Besides these, small-scale aquaculture might be extended to roadside shallow canals, jute retting ponds, monsoon swamps, flooded depressions, closed creeks, and irrigation canals. Many small-scale farmers are also practicing pen culture in river and canals which creates the dimension in aquaculture.

(ii) **Diversification of the Culture Species**

The socio-economic benefits derived from aquaculture expansion include the provision of nutrients, employment and income generation for the poor, diversification of production, and generation of foreign exchange earnings through export of high-value products (Hossain 2009). Diversification of species has been described as an effective strategy to combat lower farm-gate prices (Newton et al. 2021). The diversification in culturable finfish/shellfish in small-scale freshwater and coastal aquaculture (Figs. 14.5 and 14.6) is one of the key factors in effective resource utilization, production enhancement, increasing heterogeneity in produce, increasing sustainability, and economic upliftment of the smallholding farming community. However, illegal and/or unauthorized introduction of fishes may hamper the production of other economically important native species, which is very often the practical reality in Asian countries where cross border trafficking of live fish and shellfish has been recorded. Proper selection of suitable species should be based on agro-climatic conditions of the region and the capacity of the farmers. As most of the small-scale farmers hold very small land, therefore, they have to make sure about species selection to increase per unit production efficiency. With respect to the culture of new species, all the criteria should be good adaptive to breeding in captivity, high growth rate, and high consumer demand and high market rate.

Central Institute of Freshwater Aquaculture (CIFA) has successfully standardized and disseminated the breeding and rearing technologies of few commercially important freshwater fishes among the farmers throughout the country. Farmers have adopted the technologies and successfully produced such diverse fish species. Rural poor people mostly fulfill their nutritional demands through consumption of major and minor carps.

Among major carps, especially silver carp and common carp are the most preferable species in the rural areas because of their low price in the market which fits best to the local level customers. Species like black carp (*Mylopharyngodon piceus*), Java puti (*Puntius javanicus*), deshi tangra (*Mystus vittatus*), mola (*Amblypharyngodon mola*), pabda (*Ompok pabda*), and scampi (*Macrobrachium rosenbergii*) are being cultured by small-scale farmers through polyculture or composite culture system and should be propagated further. Along with major carps, minor fishes like bata (*Labeo bata*), reba (*Cirrhinus reba*), dero (*Labeo dero*), climbing perch (*Anabus testudinius*), mola (*Amblypharyngodon mola*), deshi tangra (*Mystus vittatus*), chitala (*Notopterus chitala*), folui (*Notopterus notopterus*), deshi magur (*Clarias batrachus*), singhi (*Heteropneustes fossilis*), punti (*Puntius ticto*, *Puntius sophore*), Java puntu (*Puntius javanicus*), boroli (*Barilius bola*), pengba (*Osteobrama belangari*), spiny eel (*Mastacembelus armatus*), murrel (*Channa striatus*), etc. have already been introduced in small-scale aquaculture at several places in India (Table 14.2).

Seed is the bottleneck of species level diversification in brackish water coastal aquaculture in many Asian countries. Most of the producers face lots of challenges

Table 14.2 Diversification in finfish and shellfish species in freshwater and brackish water

Region	Freshwater species
All the inland states of India	Catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), silver carp (*Hypophthalmicthys molitrix*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), black carp (*Mylopharyngodon piceus*), Bata (*Labeo bata*), reba (*Cirrhinus reba*), dero (*Labeo dero*), climbing perch (*Anabus testudinius*), mola (*Amblypharyngodon mola*), deshi tangra (*Mystus vittatus*), chitala (*Notopterus chitala*), deshi Magur (*Clarias batrachus*), singhi (*Heteropneustes fossilis*)
Mostly the eastern states of India	Folui (*Notopterus notopterus*), punti (*Puntius ticto*, *P. sophore*), Java puntu (*Puntius javanicus*), boroli (*Barilius bola*), pengba (*Osteobrama belangeri*), spiny eel (*Mastacembelus armatus*), murrel (*Channa striatus*), Java puti (*Puntius javanicus*), deshi tangra (*Mystus vittatus*), mola (*Amblypharyngodon mola*), pabda (*Ompok pabda*), and scampi (*Macrobrachium rosenbergii*)
Region	**Brackish water species**
All the coastal states of India	Asian sea bass (*Lates calcarifer*), milkfish (*Chanos chanos*), scat (*Scatophagus argus*), perse (*Mugil Persia*), grey mullet (*Mugil cephalus*), silver pompano (*Trachinotus blochii*) and shellfishes like tiger shrimp (*Penaeus monodon*), whiteleg shrimp (*Litopenaeus vannamei*), mud crab (*Scylla serrata*), edible oyster (*Crassostrea madrasensis*), and pearl oyster (*Pinctada fucata*)

regarding breeding of such species under captive conditions of their own. Coastal farmers have to depend upon wild collection of finfish and shellfish seeds from natural brackish water resources. The small-scale aquafarmers in the Sundarban biosphere in India and Bangladesh and coastal artisanal fishers in Indonesia, Thailand, Sri Lanka, and the Philippines used to collect seeds of finfish, shrimps, and crablets from small creeks, lagoons, and backwaters.

The breeding and seed production of some brackish water finfishes and shell fishes have been standardized by few central institutes in India like Central Marine Fisheries Research Institute (CMFRI), Central Institute of Brackishwater Aquaculture (CIBA), and Rajiv Gandhi Centre for Aquaculture (RGCA) in India. The standardized captive breeding and seed production of finfishes like Asian sea bass (*Lates calcarifer*), milk fish (*Chanos chanos*), scat (*Scatophagus argus*), perse (*Mugil persia*), grey mullet (*Mugil cephalus*), and silver pompano (*Trachinotus blochii*) and shellfishes like tiger shrimp (*Penaeus monodon*), whiteleg shrimp (*Litopenaeus vannamei*), mud crab (*Scylla serrata*), edible oyster (*Crassostrea madrasensis*), and pearl oyster (*Pinctada fucata*) have been successfully disseminated even among the small- and medium-scale farmers in the coastal states in India (Table 14.2).

Likewise in India, the small-scale farmers in Bangladesh also emphasized in captive breeding and seed production of indigenous fishes besides collection of seed of finfish and shellfish from natural rivers. Both in India and Bangladesh, it's commonly noticed that farmers spend their life on the basis of collection of good-quality fish seeds, shrimp larvae, and crab juveniles. After collection of such, they usually used to stock in their own ponds for culture purpose or sell in market to earn money for livelihood generation.

(iii) **Diversification in Cropping Pattern**

Besides production of table fish, there is enough scope of diversifying small-scale aquaculture activities by the smallholding farmers in participating fish seed rearing at different stages, viz., spawn to fry, fingerlings, yearlings, and stunted fish fingerlings in their small ponds. This should be based on actual capacity and practical situation of the farmer and obviously will be with localized pattern. This is pertinent because purchasing good-quality fry and fingerlings directly from the hatcheries is not very often possible because of a number of limitations. Therefore, small-scale farmers can diversify their activities towards self-sufficiency not only in seed resource but can also generate their livelihood and income through fry and fingerling production in the seasonal ponds within a short period of time (Fig. 14.7).

The approach of multiple stocking and multiple harvesting of fish by the small-scale farmers to increase their productivity and yield will be another option of cropping pattern diversification. However, regular availability of seed is considered as one of the major bottlenecks in adopting such pattern in many areas. Therefore, seeds of different stages up to stunted fingerlings if produced by the small-scale farmers themselves, this bottleneck might be overcome. Smallholding farmers may adopt cluster farming approach in this regard as number of water bodies required will be high. Suresh Babu et al. (2019) reported that stunted fingerlings are less vulnerable to predation and diseases and are more tolerant to environmental fluctuations; they require less time to reach marketable size leading to higher production through low input cost. The community village ponds and the water bodies mostly seasonal water bodies which are not properly managed and utilized for fish production due to non-availability of good-quality and quantity seed. Water is

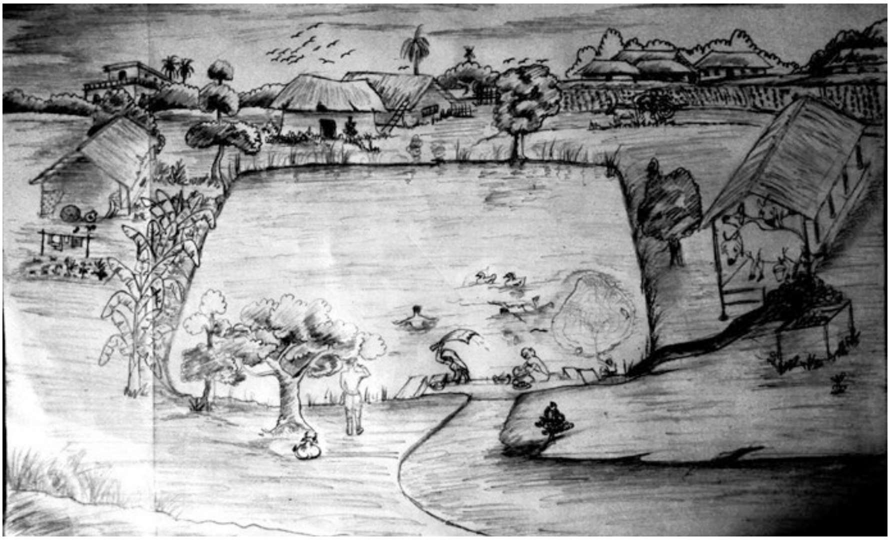

Fig. 14.7 Portrait of small-scale aquaculture in rural areas

available only during the monsoon season. So, production of stunted fingerlings within 4–5 months provides an opportunity for small-scale farmers to generate more additional income (Jodhavgai et al. 2017).

Lack of access to land and water typically constrains the resource poor from benefiting directly from aquaculture (Lewis 1997), and the hatchery sector tends to be dominated by entrepreneurs and wealthier farmers (Barman and Little 2006). The in-pond net-cage culture system which is mainly hapa based rearing of fish seed and management of feeding ration helps to achieve higher production in small- and marginal-scale operation in the rain-fed areas. In such areas, demand for fish seed peaks early in the wet season in synchrony with seed production from hapas suspended in perennial water ponds. Such hapa-based fish seed production is a very popular mode in a number of Asian countries like China, Bangladesh, and India (Bardach et al. 1972; Beveridge 2004). Nursery rearing of small fry in hapas to larger, more predator-resistant fingerlings is contributing significantly to the whole aquaculture sector in general (Edwards et al. 1990; Haitook et al. 1999).

Integrated aquaculture offers an opportunity to increase farm productivity for poor small-scale producers who are not well connected to input and output markets. Integrated system, enabling aquaculture through on-farm synergies of agri-husbandry crops and fish farming, has been proved to be an effective strategy in improving efficiency, productivity, and augmenting farmers' income (Dey et al. 2006; Nhan et al. 2007). In small-scale aquaculture practice, the system in most cases is integrated with horticultural crops on the embankments and homestead husbandries of duck, cattle, and others. Both the increased availability of fish as source of animal protein as well as the higher income subsequently results in higher food consumption and better nutrition of the household members. The technology offers farmers economic improvements through the recycling of unused or renewable resources for production which helps in promotion of diversity and sustainability and enormous potential different areas of the countries (Dey et al. 2010). The technology also helps in diversification and higher cropping intensity (Prein 2002).

Besides fish production, diversification in cropping pattern is also practiced by small-scale aquafarmers in rural areas in most of South Asian countries like India, Bangladesh, Nepal, and Myanmar producers. The road side shallow water bodies and village level community ponds might be used for production of lotus (*Nelumbo* sp.) flower and leaves, edible leafy vegetables (*Ipomia* sp.), edible gastropods (*Bellamya* sp.), and freshwater mussel (*Unio* sp.). Small pond snails and gastropod (*Bellamya bengalensis*) are also considered as good source of low cost protein for rural peoples in India, Nepal, and Bangladesh. Freshwater gastropods play an important role in the dynamics of aquatic ecosystems and commonly found in tanks, ponds, beels, reservoirs and rivers, stagnant water bodies, and irrigated paddy fields (Saha et al. 2017). Such aquaculture produce in the Asian countries are mostly under reported though they are significant sources of income generation and play important roles in supply of good-quality protein for the rural people without involvement of significant operational cost. The women members of rural family are very enthusiastic in harvesting and marketing such produces.

Lotus flowers have religious significance for the Hindus and Buddhists as well. The fruits, seeds, rhizomes, and stems of water lilies are consumed by rural people in South-East Asia and India as vegetables and salad (FAO 2009). Indian lotus (*Nelumbo nucifera*) and water lilies are common aquatic macrophytes which usually grow naturally in shallow water bodies. In the Eastern part of India, viz., West Bengal, Assam, Tripura, Bihar, Orissa, Andhra Pradesh, and Telangana, cultivation of water chestnut (*Trapa* sp.) in roadside and railway track side ditches during the monsoon months through fall is an important small-scale economic activity that doesn't require investment and any special management. Like water chestnut, swamp morning glory (*Ipomoea* sp.) which is considered as a leafy vegetable in South Asia is being cultivated by the small-scale farmers not only in swampy areas but also as a secondary crop in aquaculture and agriculture. The cultivation of makhana (*Euryale ferox*) by the small-scale farmers in shallow water bodies is very popular in states like Bihar, Jharkhand, some parts of Orissa, and West Bengal in India. Makhana has good market demand due to its rich nutritional quality. *Azolla* is also a good source of protein (19–30%) compared to green forage crops and aquatic macrophytes. Due to its essential amino acid (EAA) composition, it is attracted the attention of livestock, poultry, and fish farmers (Cagauan and Pullin 1991). Many small-scale farmers in South-East Asian countries used to cultivate *Azolla* in shallow water bodies. Besides these, smallholding farmers also utilize their seasonal pond beds for production of vegetables like pumpkin, bitter gourd, Malabar spinach, lady's finger, etc. which act as additional supplementary crop in rural areas.

(iv) **Diversification in Culture Inputs**

In densely populated Asian countries, scope of expanding farming area is becoming limited, and therefore, feeding the growing population has to be accomplished by improving the productivity of currently farmed area (Murshed-E-Jahan and Pemsl 2011). Inputs are the key factors along with others in increasing productivity irrespective of intensity of operation in aquaculture. The common inputs in rural smallholding aquaculture mainly comprised of organic inputs like cow and buffalo manure, poultry litter, pig dung, vermicompost, etc. and locally available low cost agriculture left-over as feed ingredients, viz., rice and wheat bran, and oil cakes, viz., mustard oil cake, groundnut oil cake, sesame oil cake, mahua oil cake, etc. Besides these, broken rice, residues of pulse milling, low-grade molasses, biscuit crumbs, rice water, whey, and floor waste of flour mills are also recent addition towards diversification of inputs in small-scale aquafarming in the rural areas. For feeding grass carps aquatic macrophytes, viz., *Hydrilla* sp., *Naza* sp., *Lemna* sp., and napier grass, are used by the farmers. In Indonesia, small-scale rural farmers use Colocasia stem as feed for the Pangasius. Culture and use of Black soldier fly as protein-rich live feed in the small-scale aquaculture has already been popularized in Indonesia and Thailand which has also been introduced in some parts of India. The majority of farmers practice traditional, extensive, or modified extensive system through utilization of cow dung as organic manure and oil cake which primarily act as feed as well as fertilizer upon decomposition to enhance nutrient level in pond water. The poor management facilities and low or no input of commercial feed which improves the culture efficiency.

(v) **Diversification in Culture Ecology**

Ecological aquaculture is considered as an alternative model of aquaculture development to utilize ecological principles (Costa-Pierce 2003). Ecological aquaculture farms are designed to deliver both economic and social profit to integrate aquaculture ecosystems (Costa-Pierce 2013). Small-scale aquaculture diversification must be compatible with local agroecological systems to reduce pathogen and predator risk and promotion of the local aquatic biodiversity (Pullin 1993). Changing climate forces to introduce and examine the potentiality of newer fish species for sustainability of inland aquaculture. The diverse ecological niches where only limited volume of aquaculture production can be obtained, however, such niches in other hands might be advantageous offering competitive advantages for variety of fish production (Gurung et al. 2018).

(vi) **Diversification in Markets**

The concept of market and marketing the aquaculture produce of the small-scale farmer has been changed parallel with growing economy, connectivity in terms of communication, and transport. Now the farmers have easy access to the urban and semi-urban organized market without much difficulty. They are also better equipped with electronic gadgets so as to be informed of the market volatility in and around their locality so as to choose marketing option. Therefore, regarding selling their produce in excess of their own consumption, small-scale aquafarmers are not facing uncertainty unlike the earlier days when at times they have to exchange their aqua products with other agricultural crops as a barter system of marketing in the rural areas. Although such system was beneficial to both the seller and the purchaser as both have monetary constraints being positioned in the same lower level economical strata, however, the main reason by the small-scale farmers for selecting certain markets that is easily accessible and near the farm is that they don't have enough money to transport their small quantum of produce in a far-flung market even if the market price is significantly higher. Farmers need support to help them identify and access high-value markets through a combination of market information and effective business and production planning skills to improve cash forecasting.

(vii) **Women Empowerment**

Rural aquaculture is considered as the potential tool to combat poverty and malnutrition. Women are critical as agents in achieving food security and improved nutrition in poor and vulnerable households (FAO 2021). Women sector is having great potential and can be exploited through small-scale aquaculture practices. Globally, both public and private sector are promoting small-scale aquaculture among women through training and demonstration through different organizations by dissemination of scientific fish farming practices. Though ownership of farms is still largely male dominated, the women members of smallholding aquafarming families might be allowed to take part more effectively in their family enterprise of fish farming. Already the women folk of farming families are performing well as family laborers in small-scale aquaculture as they play numerous roles in pond preparation, feeding, packing, marketing, etc. The women empowerment by creating ownership and providing technical guidance and providing suitable inputs, the production can be further enhanced and their contributions increased considerably. In South-East Asian countries, women are actively engaged in small-scale aquaculture practices like ornamental fish breeding and culture, collection and preparation of freshwater pearl, collection of seaweed in coastal areas, culture of finfish and shellfish in inland and coastal water, etc. (Gopal 2017).

8 Constraints of Diversification in Small-Scale Aquaculture

With the growing rural population and large number of dependents per family, land inheritance leads to a pluralistic ownership of fishponds, presenting an array of issues related to co-ownership and collective action among heterogenous shareholders. As a result, many of the underutilized or derelict fishponds have been resulted from the social dimensions of multiple ownership, when cost sharing, benefit distribution, assignment of responsibilities and accountabilities, and involvement in the pond management become a chaos. Marginal farmers with land access of 0.2–0.5 ha can still benefit from small-scale aquaculture, but they have multi-pronged constraints in accessing resources. Without access to land and water, the poorest are unlikely to engage in fish farming directly where many of the village level ponds are recognized as community pond. The main drawbacks of those ponds are usually focusing non-utilization of those resources without sustainable management. However, some fishpond owners may also be categorized as medium-sized landholders, those who possess 1–2 ha of land, produce some surplus, and employ seasonal wage laborers. Therefore, training facilities should be provided to grow interest among multi-owners of pond about the proper management and profit sharing in aquafarming. Farmers must be encouraged to the aquaculture practices with integration approach to obtain higher production through effective utilization of available resources to enhance the socio-economic status (Pall et al. 2018).

The small-scale farmers were unorganized, and most of the farmers did not have access to technological innovations and scientific applications, though they are innovative and productive. However, because of poor organization, lack of skills, inadequate information, and knowledge base, they are vulnerable to the numerous risks and hazards that impact their livelihoods, farm productivity, and competitiveness (Umesh et al. 2010). The most serious constraint is the absence of aquaculture production technologies and the shortage of sustainable quality fish seeds and feeds supply. Besides, social taxation and bulling for extortion that has seldom been documented is also a major constraint to the small-scale farm holders in many Asian countries. The consequences of such often lead to poisoning the pond resulting in total crop loss of the small-scale aquafarmers.

In general, small-scale aquaculture farming communities are constrained with (i) lack of start-up capital (Awulachew et al. 2008), (ii) technical abilities (Mkoka 2007), (iii) family support (Verheul et al. 2006), (iv) government support (Das 2006), (v) training provided by local government (De la Cotera 2001), (vi) farming experiences and knowledge (Das 2006), (vii) potential market (Sukadi 2006), (viii) low selling price (Effendi 2008), (ix) low profits (Zainal 1998), (x) low quality and quantity of fish seed (Mantau et al. 2004), (xi) low quality and quantity of fish feed (Bueno 1999), (xii) poor financial management skills (Theng and Boon 1996), (xiii) poor quality control and low ability to handle fish disease and parasite (Sukadi 2006), (xiv) poor water quality (ADB 2015), and (xv) inability to secure sufficient loans (Nam and Thuok 1999).

However, Elfitasari and Albert (2017) documented the constraints in small-scale aquaculture sustainability as:

1. Managerial constraints in water quality examination, inability in securing sufficient loans.
2. Lack of family support to develop and implement sustainable aquaculture in order to achieve product sustainability.
3. Lack of potential market of fish that have limited shelf-life.
4. Lack of support and training to support small-scale fish farmers provided by the government.
5. Lack of fish farming experience and knowledge make the barrier to implement sustainable aquaculture as they do not have sufficient experience and knowledge of the practices.

However, these constraints may not be equally applicable everywhere, because most of the traditional small-scale fish farmers have sufficient experience in this sector through generations in Asian countries and they have been proved innovative (Biswas et al. 2018).

9 Strategies of Diversification Goals

As the socio-economic, agro-climatic, and logistic attributes of the SSA farmers are highly variable from region to region along with the governmental policies and supports towards SSA, fixing generalized goal might lead to nowhere. Therefore, localized planning giving proper stewardship to the farming community themselves with technical back-up from the competent agencies should be a practical approach in diversifying SSA. The most important strategy in this regard is to give emphasis on local human capital including the acquired experience and skill of the farming communities. Cluster farming approach links 20–75 local farmers in groups forming into voluntary alliances with group farms using agreed-on management practices. Such cluster farms can use their collective strength in financing and in marketing their crops cooperatively.

Diversification strategies with any or all of the attributes in SSA is multifaceted, and these are suggested herein:

(i) Creation and achieving more synergy among stakeholders and policy makers.
(ii) Selection of area-specific progressive fish farmers to make and operate in model fish farm.
(iii) Appropriate need based hands-on training on species selection, cropping pattern, pond preparation, nutrient management, and disease control taking into account the particular ecological condition of the farmer concerned.
(iv) Area-specific functional approach of integrated farming for achieving better economic sustainability.
(v) Up-scaling feeding practice from the traditional one and improvement of feed quality.
(vi) Motivating the farmers about the need for conservation of the indigenous small variety of fish in their culture ponds focused both on ecology and economy.
(vii) Removing bottlenecks towards accessing capital as loans and subsidies, and its repayment terms from banks and micro-financing institutions.
(viii) Providing institutional supports for overall socio-economic upliftment, viz., housing, education to the farm holder's children, health care, etc.
(ix) Removing political bias towards the farmer in getting equal benefit from government and non-government agencies.
(x) Prohibiting random and indiscriminate use of organic waste, raw slaughter house refuge, offal, and what-not that very often invite disaster in the culture pond.

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Chapter 15
Value Addition in Meat and Fish Products for Human Health and Nutrition

A. R. Sen, B. M. Naveena, Rituparna Banerjee, and M. Muthukumar

Abstract Processing meat or fish into value-added products produces a variety of ready-to-eat or cook products. Recent advancements in processing technology are aimed at its upgradation, diversification, and ensuring quality. Value-added meat or fish products are further processed and convenient to prepare the food items. Different processing and cooking methods are employed to produce a variety of value-added products. The quality of end products depends on raw material quality, formulation, and processing knowhow. A variety of meat products is available around the world depending on the process, consumers' food habits, and acceptability. Emulsion meat products like sausage, salami, frankfurter, etc. are very common worldwide. Shelf stable retortable pouches are very popular nowadays as they require no refrigeration. Several value-added fish products like fish sausage, cutlets, patties, balls, pastes, surimi, texturized products, etc. can be produced from minced fish. Many traditional meat and fish-based products are widely consumed throughout the world. The products follow ethnic processing methods, and depending on regional taste it plays a significant role in value addition and nutritional security. Recently, few advanced non-thermal processing methods like high pressure processing, infrared and sous vide processing, etc. are also becoming popular due to their unique nature of processing which suits the environment and energy saving also. Functional or designed meat products are able to exert extra physiological health benefits beyond its nutritional composition. The present chapter gives an insight into traditional and recent advancements in the processing and value addition of meat and fish.

Keywords Meat · Fish · Human health · Nutrition · Urbanization

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_15

1 Introduction

The utilization and sustained livestock production provide livelihood and nutritional security to a large sector of global population. Meat and fish products contain healthy compounds, like iron, zinc, conjugated linoleic acid (mainly in ruminant), and other nutrients including vitamins, and other body building ingredients. Processing meat or fish into value-added products produce a variety of ready-to-eat or cook products. Recent advancements in processing technology are aimed at its upgradation, diversification, and ensuring quality. The rising affluence and changing eating habit have resulted in a need for a variety of processed and convenient products from meat and fish. The growing trend of eating out has further fueled the growth of fast-food industry serving value-added meat and fish products. The rapid industrialization coupled with urbanization provides ample opportunity for the development of domestic markets for such products. Increasing number of working women, nuclear family, increasing education, and general consciousness about health are the other favorable factors. The optimum wellbeing from healthy meat/fish product is to maintain a disease-free life. Nowadays, consumers are more concerned about their health, and different functional/designer meat products are available with added health benefits to the consumers beyond their inherent composition.

2 Value Addition

Value addition can be defined as a process which increases the usability, improving culinary attribute, or contributes economic viability of a food item in the supply chain. Value-added meat or fish products are further processed and convenient to prepare the food items. These are broadly classified based on processing, variety/convenience, and function. Different processing and cooking methods are employed to produce a variety of value-added products. The quality of end products depends on raw material quality, formulation, and processing knowhow. The successful marketing of such products with better return is possible if storage, packaging, and labelling are properly followed. In general, the purpose of value addition is to produce a variety of meat products of convenience to increase demand and marketability. It also helps in employment generation and ensure easy transport and distribution to a large number of consumers and helps in preservation.

3 Value-Added Meat Products

Technology of meat processing brings an alteration in biochemical, technological, and microbiological quality of end products. Hygienic handling of meat, fabrication of different cut-up parts, and preservation by chilling or freezing are not a part of meat processing. Value addition involves a wide range of processes – particle size reduction (chopping, mincing, sectioning, chunking, flaking), tumbling, massaging, and stuffing – and chemical or biochemical processes: curing or salting, smoking, drying, fermentation, etc. Novel processing approaches for newer product development which are innovative and cater to the need of present consumers. A variety of meat products available around the world can be grouped into seven categories based on their product characteristics and the general processing procedures required (Table 15.1). Based on their processing method, meat products may be roughly classified into 8–10 groups (Table 15.2). Meat and meat products may also be classified based on their functions and requirements into functional/designer meat products, geriatric products, institutional products, etc.

3.1 Particle Size Reduction

In further processing of meat, reduction of particle size is a very important step in new product development. Meats containing moderate to high levels of connective tissue should be reduced to fine particle size to ensure uniform palatability. Particle size reduction may be accomplished by sectioning, chunking, slicing, flaking, grinding, or chopping (Kondaiah 2004). Reducing the meat particle size of meats

Table 15.1 Classification of meat and meat products based on variety

Meat product	Processing/characteristic features	Example
Canned meats	Retort to sterilize; fully cooked; cured or non-cured	Corned beef, Vienna sausages, beef stew
Frozen meats	Cooked or raw; mostly microwavable	Breaded cutlets or burger patties, meat loaf, meat balls
Dry-preserved meats	Low water activity; cured; refrigeration not required	Beef jerky, pastrami
Cured meats	Cured with salt, nitrite, and other adjuncts by injection or dry rub	Hams, bacon, deli meats
Sausages	Fresh, cured, or fermented; comminuted or emulsified	Frankfurter, salami, pepperoni, hot dogs
Dinner meats	Prepared meals; pumped products; battered/ breaded meats; precooked or raw; frozen or refrigerated	Steak with vegetables; seasoned pork roast
Luncheon meats	Deli meats; fully cooked and ready to consume; restructured meats	Sliced ham, bologna, and salami

Source: Hui et al. (2001)

Table 15.2 Meat and meat products based on processing method

Product type	Examples
Sectioned and formed meat products	Beef rolls, Turkey rolls, boneless hams, etc.
Emulsion meat products	Nuggets, meat balls/kofta, emulsion sausages
Restructured meat products	Restructured meat loaves/slices
Ground meat products	Ground meat patties
Enrobed meat products	Enrobed wings, drummettes, enrobed patties
Cured and smoked meat products	Ham, bacon
Dried meat products	Beef jerky, pastrami
Canned/retort pouched meat products	Vienna sausages, corned beef
Fermented meat products	Salami sausages

Source: Sen et al. (2012)

increased surface area and exposure to atmospheric oxygen and other contaminating materials. This leads to higher lipid and myoglobin oxidation and reduction in microbial quality of meat. Therefore, the temperature of the meat and the processing room should be maintained at 7 °C and 12 °C, respectively. Few processes for particle size reduction are described below:

Flaking During processing of steaks and other restructured products, comminution is done by flaking. The quality of end products depends on the size of the flake. Size reduction is performed in two stages where pre-breaking is initially performed, and then meat is forced through the flaking heads of different sizes and meat particle sizes are reduced.

Mincing Mincing is a technique in which whole meat/fish chunks are made into very small pieces. Meat mincing/grinding is done onto a rotating spiral shaft wherein boneless chunks are fed. The meat is then pressed against a rotating knife and through a plate with holes of different diameter (1.5–13 mm). A meat mincer grinds semi-frozen or preferably partially thawed meat and produces minced meat. The lower temperature should be maintained for effective mincing process. Mincing mechanically disrupts the course muscle fibers especially myofibrillar and connective tissue and used for finely comminuted meat products.

Chopping Chopping is usually done in bowl chopper or silent cutter. A bowl chopper has a rotating bowl where meat and other ingredients are mixed for emulsion making along with rotating knives which further cut the meat pieces for getting uniform mix. Heavy duty mixers used in households also work with same mechanism, but with lower capacity. Bowl choppers are usually used in the preparation of emulsion meat products. The degree of particle size reduction is limited in mincing, whereas bowl chopping involves cutting through myofibrillar and connective tissue fibers several times with very sharp knives.

3.2 Emulsion Meat Products

Meat emulsions are prepared by mixing meat, fat, and water with the addition of other non-meat ingredients until a fine batter is formed. This protein matrix then binds fat, water, and other non-meat ingredients. A meat emulsion is a fat-in-water emulsion, where fat is the discontinuous phase and the solubilized protein constitutes the continuous phase (Dickinson 2012). In the meat emulsion, the solubilized muscle protein acts as an emulsifier. The myofibrillar proteins have strong binding properties than sarcoplasmic proteins. During emulsion preparation, salt and phosphates increase the myofibrillar protein solubility and hold water very strongly. Emulsion meat products like sausage, salami, frankfurter, etc. are very common worldwide. The traditional emulsion meat products contain up to 30% fat though vary depending on the product type. Fat plays significant roles in emulsion preparation by stabilizing it and reducing cook loss and improving the textural properties (Choi et al. 2010).

3.3 Restructured Meat Products

Restructuring is the disassemble of meat chunks and then reformed into the same or a different form. All varieties of sectioned and formed meats and ground and comminuted meat products form into this category. However, processing methodologies may differ depending on the products and uniqueness for the particular products. The chunked, ground, or flaked meat pieces are used in restructured meat products wherein proteins extracted by using tumbling/massaging enhance the binding of meat proteins. A small amount of non-meat binders can be used for better binding along with other ingredients (Reddy et al. 2013).

Restructured meat products consist of either minced meat or loose meat pieces which are bound together using a binder. These products allow underutilized cuts and quality trimmings can be used for value addition. These restructure meats have been developed for producing new products, and upgrading and utilizing meat, which is considered to be lesser economic value. Hot set or cold set binding systems are generally used for producing such products. The binding of meat pieces in such products is achieved by the formation of gels through hot set binding or chemically in cold set binding (Boles and Shand 1998).

3.4 Ground Meat Products

In this type of products, meat is minced or ground and mixed with fat and other non-meat ingredients in a mixer or massager. Meat proteins are extracted by slow massaging and mixing and facilitate binding the meat pieces with other ingredients to form a tacky mix. The mixture is then stuffed in casings for preparation of ground meat sausages or patties for using in burger. In such products, no emulsion is formed as bowl chopper is not used during this processing. As more surface area is exposed to atmospheric oxygen, these are more prone to oxidation or microbial contamination. Therefore, antioxidants are sometimes used to increase the storage stability of such products. The low-value cuts and trimmings can be utilized properly for processing of ground meat products (Zhao and Sebranek 1997).

3.5 Enrobed Meat Products

Enrobing, one of the most popular methods of value addition, is the process of applying an edible coating material around meat and fish products for developing better sensory properties and nutritive value (Ahamed et al. 2007). It also improves the sensory quality of the product, and nowadays getting better consumer acceptability. Coating reduces moisture and weight loss during cooking, improves their cooking yield, juiciness, and tenderness, and preserves the nutritive value. The edible coatings also increase the shelf-life of enrobed meat products preventing oxidative and microbiological deterioration (Biswas et al. 2004).

3.6 Cured and Smoked Meat Products

This type of value-added processed meat products comprises of two processes, i.e., curing and smoking:

Curing Curing is the oldest method of meat preservation which is practiced globally. In curing, deboned or with bone meat cuts are either immersed or injected with curing brine or pickle solution. The curing solution consists of salt, phosphate, nitrate/nitrite, ascorbate, and sugar dissolved in potable water, which is also popularly known as brine (Ahmad et al. 2005). Each ingredient has their own role and imparts unique cured meat flavor and attractive pink color and improves the product safety. The chemical reaction between nitrites and meat pigments produces the typical cured meat color and flavor and also has antioxidant and antimicrobial activity. The antimicrobial activity is mostly for inhibiting *Clostridium botulinum* and widely known as antibotulinal effect. Curing also inhibits other pathogens such as *Listeria monocytogenes* which is very important in ready-to-eat processed meats (Sullivan 2011). In general, there are two types of curing methods: wet and dry. In wet/pickle curing, the meat cuts are either dipped or injected with curing solution. Injection curing helps in uniform distribution of curing solution and hastens the development of attractive cured meat color. In dry curing, all the curing ingredients are rubbed over the meat surface and stored for a prolonged time under controlled temperature and humidity for improving quality. In this curing method, the distribution of brine solution is not optimum, and very often gray spots are observed.

Smoking It is the application of vaporous or liquid smoke to meat or fish for making value-added products with unique color and taste. It creates dried meat surface and imparts a pleasant flavor. It also improves the color of the meat and oxidation of fat is prevented. Two types of smoking are generally used in processing of such products, one from natural wood and another one is from liquid smoke. Hardwood sawdust, woodchips, or sometimes from wooden logs are used for producing smoke. Different hardwoods such as hickory, oak, maple, ash apple, cherry, etc. are commonly used for smoke generation. Liquid smoke is manufactured by water permeation-distillation process of the condensable fraction of natural wood smoke. The application of smoke can be employed through dipping meat chunks or spraying to the surface of the meat products. A variety of cured and smoked products like bacon, Canadian bacon, corned beef, hams, country hams, Prosciutto (parma) hams, Westphalian (German) hams, etc. are available in the market.

3.7 Dried Meat Products

Low moisture and intermediate moisture meat generally come under dried meat category. The products having a water activity (a_w) of <0.60 and containing <25% moisture are defined as low moisture meat whereas intermediate moisture meat contains less than 50% moisture with a water activity ranged from 0.60 to 0.85. The dried product which contains less than 10% moisture is shelf stable at ambient temperature. The drying of meat depends on the shrinkage, rehydration ratio, diffusion behavior, etc. of the product (McMinn and Magee 1997). In general, drying controls the growth of microorganisms by lowering the a_w of food product (Thiagarajan 2008). Whole muscle or emulsion type meat products can be dried to make the product shelf stable. Different methods of drying can be applied by modifying temperature, freeze drying, or it can be solar dried. Beef jerky (American), Biltong (African), pastrami (Turkey), charque (Brazilian), bologna (Lebanon), Genoa (Italian), etc. are few dried meat products available globally (Dincer and Erbas 2019). Dried meat products are shelf stable and requires less storage space and transport cost, and most importantly it can be utilized in natural disasters such as cyclones, floods, earthquakes, etc. The shelf-stable dried meat plays a significant role especially in developing and underdeveloped countries for animal protein security. As no refrigeration is required during storage and marketing channel, such products have a great potential where the cold chain facility is lacking (Mishra et al. 2017).

3.8 Canned and/or Retort Pouched Meat Products

Canned meat products are prepared in metal container which is hermetically sealed and thermally processed to destroy spoilage microorganisms. The sterilized products are shelf stable as the product temperature reaches to 101 °C during processing. In commercially sterile canned meat products, viable microorganisms along with spores are destroyed. Three main operations during canning are can filling, exhaustion, and heat treatment. Canned meat products are processed in retort under 12–15 psi pressure and a temperature of 121 °C. Nowadays retortable pouches are more popular than metal can as it can withstand high temperature and pressure. Pouches are impermeable to gases and moisture, and their lighter weight enables easy distribution and marketing. Products in retort pouch are processed in a way similar to canning and are shelf-stable (Dileep and Sudhakara 2007). The pouches are multilayer laminated comprising of polyester film/aluminum foil/polypropylene. As compared to the can, the flatter shape of retort pouch enables a uniform heat transfer, and less heat is required to reach the safe temperature in the geometrical center of the product (Dushyanthan 2002).

3.9 Fermented Meat Products

Live lactic acid bacteria are used for fermentation in such products after mixing with minced meat, fat, and other non-meat ingredients. The various species of lactic acid bacteria such as *Lactobacillus lactis*, *Leuconostoc* sp., and *Bifidobacterium* sp. are commonly used as starter culture in processing of fermented meat products. The mixture is then stuffed and cooked under controlled temperature and humidity. These starter culture organisms produce major antibacterial compounds, and resulting lactic acid and lower pH inhibit the growth of pathogenic bacteria. The unique taste and flavor are produced due to acidulation during fermentation and ripening. Reduced pH and lowering of water activity enhances the shelf-life of these products (Laranjo et al. 2019). Semi-dry and dry sausages are classical examples of fermented meat products. These are prepared from fresh meats that are cured during processing and can be smoked or without smoking, and fermentation is done in a controlled environment. Probiotic meat products have a potential in functional food market as they provide health benefits to the consumers. Therefore, the fermented meat products can play a major role in this sector as live bacteria can produce many bioactive compounds for consumers' health and wellbeing (Khan et al. 2011).

4 Value-Added Fish Products

Several value-added fish products like fish sausage, cutlets, patties, balls, pastes, surimi, texturized products, etc. can be produced from minced fish (Sen et al. 2015), and few of them are very much potential for starting small-scale industries for entrepreneurship development.

4.1 Surimi

Surimi is a Japanese term for deboned fish flesh which is washed with water, and cryoprotectants are added for increasing frozen shelf-life. Washing in the surimi preparation removes fat and other undesirable matters such as blood, pigments, etc. from flesh. The gel strength and elasticity of the product is improved due to increased concentration of proteins. White muscled fish species are generally used for making surimi. The desirable color and odor and gel-forming characteristics of the surimi are essentially required for producing crab leg analogue (Oshima et al. 1993).

4.2 Fish Fingers

It is a very popular product and prepared from minced fish. During preparation, generally 80% of minced fish are used, and other ingredients like salt, sugar, spices, and condiments are added at 20%. Frozen mince is cut into finger shape, and the other ingredients are applied as paste. The fish finger is then coated with batter followed by breading for making a crispy taste. The fish fingers can be frozen and stored for further use. The frozen fish fillets are used as raw materials in this breaded product (Oehlenschlager 1995). The fish finger produced from rohu species can be stored up to 15 days at 4 °C without marked quality deterioration (Praneetha et al. 2016).

4.3 Fish Burger

Burger is processed from ground meat of white fleshed fish. The minced meat is cooked and mixed with boiled potato, spices, condiments, and other non-meat ingredients. The mix is then shaped into flat round and are battered, breaded, and flash-fried in heated oil. Fish burger is a popular and delicate item in fast food chain. The fish burger can be stored up to 72 h at 4–5 °C without any quality deterioration (Ejaz et al. 2009). It is a simple and low cost technology for converting minced fish into convenient and variety products. Fish patty/burger can be enriched with fish protein concentrate (FPC). Though the FPC added at higher level reduce the shelf-life of patty, however, at 5% FPC level it does not affect the quality of burger during storage (Moosavi and Khanipour 2018).

4.4 Fish Cakes

This is a paste type product commonly prepared from tuna and mackerels. After dressing and cleaning the fishes, these are steam boiled and separated in layers. Layered fish are mixed with boiled potatoes, salt, pepper, and citric acid and packed in vacuum to prepare fish cakes. Fish cakes are highly consumed in Korea and defined as a processed marine product containing salt-soluble protein. In South Korea, fish cakes are generally made by frying though it can be prepared by boiling or broiling (Hwang et al. 2013). Fish cakes are also prepared with different functional ingredients such as fiber, mushrooms, and anchovies for making the product healthier (Bae and Lee 2007). The product could either be frozen for further use or can be sold as fast food item in a restaurant. Fish cake processing can also be a viable commercial venture (Olayinka et al. 2009) in business development and for increasing protein security.

4.5 Fish Fillets

Fillet making is one of the best ways for value addition in fish. Fillets are prepared from white lean fish after skinning and removing the bones. It can be dipped in brine solution to improve the color and taste of the products. It has limited shelf-life as fish muscles are directly exposed to air. Immediately after processing it is required to store fish fillets at low temperature to increase the shelf-life (Rao et al. 2013). Icing could be a suitable method to enhance the storage stability of fish fillet (Mousumi et al. 2017).

4.6 Individually Quick Frozen (IQF) Products

Individually quick frozen products are a major development in freezing shrimp/prawns to maintain the quality as compared to conventional block freezing. The different varieties of finfish are also processed in the individually quick-frozen form. These products are costlier than conventional block frozen products and fetch more value. The raw materials should be of superior quality and must be stored at −30 °C or below to maintain the quality. Thermoform molded trays with shrink wrap are widely used for IQF products. The cold chain should be maintained throughout the transportation and distribution of these products. The melting of the individual pieces will stick together and form lumps if cold chain is broken. The surface dehydration is a serious problem during frozen storage of IQF products (Nakazawa and Okazaki 2020). The frozen seafood by IQF technology can be thawed in a few minutes or even cooked directly from frozen state.

4.7 Coated Products

The coated products from a variety of fish and shellfish are very important value-added products. It is a more convenient product and widely accepted by the consumer for its crispiness and juiciness. These products are dipped in a batter and then coated with bread crumbs which reduce the cost of the products (Das and Nagalakshmi 2014). Depending on the consistency of the batter, the coating process can be increased for its more crispiness. Forming and pre-dusting are the important process in the production of battered and breaded products. The shrimp, squid, etc. are widely used for development of a variety of battered and breaded products.

4.8 Fish Pickles

Pickling is an ancient practice of preservation to enhance keeping quality of foods with unique flavor. Among different preservation methods, it is easy for short-term storage of fishes. The pickles are stable at room temperature due to its low moisture content and reduced pH. Pickling is a very good method of preservation and also retain the wholesomeness and nutritive value of the product for a longer time. Fish pickle can be prepared following a variety of methods depending on regional taste (Muralcedharan et al. 1982). Fish pickle prepared hygienically with addition of salt, preservatives, and spices have an average shelf-life of 1 year. Most of the sea fishes like prawn, tuna, pomfret, and mackerel are ideally suitable for making fish pickles (Vijayan et al. 1982). Seafood pickles processed with edible oil, salt, and spices have longer shelf-life of more than 6 months at ambient temperature (Chandrasekar 1979).

4.9 Fish Meat Ball

Fish meat balls are generally prepared from low-valued fish mixed with starch, salt, and spices. This mix is then molded into ball shape and cooked in boiled water. The cooked balls can also be battered and breaded for better taste and convenience. The type of fish and mince used in processing of fish balls is important for maintaining product quality and shelf-life. Fish ball in curry can be thermally processed in a suitable fluid medium for increasing the shelf-life. Fish ball in curry was acceptable and maintained the quality up to 9 days stored at 0 to −2 °C (Kolekar and Pagarkar 2013).

5 Advanced Technologies for Meat/Fish Processing

5.1 Functional Meat Products for Human Health

Functional or designed meat products are able to exert extra physiological health benefits beyond its nutritional composition. The designed meat can be produced by enriching with healthy fatty acids, minerals, and other functional ingredients through animal dietary strategies (Table 15.3). The functional ingredients, dietary fibers, lactic acid bacteria, bioactive peptides, etc. can directly be added into the formulation during processing of value-added meat products.

Dietary fiber consisting cellulose, hemicellulose, lignin, and other components is an important ingredient for functional meat product development. An adequate fiber diet has a variety of specific healthful benefits, and the gastrointestinal physiological function is the most important for the consumers (Sen et al. 2008). The most important property of fiber is its ability to bind water and increase the water holding capacity. The fibers can be used in restructuring of products, and the uses of these fibers can help to achieve the optimum texture in such products (Verma and Banerjee 2010). Edible seaweeds contain many bioactive compounds such as polysaccharides, phenolic compounds, omega-3 fatty acids, vitamins, and minerals. Incorporation of whole seaweeds in meat products improves nutritional quality. In seafood processing, dietary fiber can directly be added to improve the water binding, emulsifying capacity, and gel-forming properties (Borderias et al. 2005).

Long chain polyunsaturated n-3 fatty acids (PUFA) are considered as critical nutrients for human health, and it can be added for development of healthy meat products. Addition of omega 3 fatty acids into food can cause off flavor and can be prevented by microencapsulation.

The demand for low fat meat products has greatly increased in recent years as saturated fats are responsible for risk of many human diseases. However, reducing

Table 15.3 Strategies for improving functional value of meat and meat products

Animal production strategies	Meat processing strategies
Production of lean meat	Enriching meat with fiber and healthy fatty acids
Alteration in fat and fatty acids content of meat	Fortification of meat products with essential vitamins and minerals
Increasing healthy fatty acids in meat	Ingredients with antioxidants and phytochemicals
Enriching animal diet with essential vitamins and minerals	Processing with bioactive peptides and probiotics
	Low fat and nitrite-free meat products

Sen et al. (2008)

the fat content in meat products has negative impact on product quality since fat contains all the flavor compounds and it improves the texture and sustained juiciness of products (Colmenero 2000).

Since meat and fish particularly white meat like poultry and pork are very much prone to rancidification, several natural antioxidants are used to prevent it. Different plant and fruit extracts such as rosemary, tea, pomegranate, etc. contain natural phenolic compounds which have significant antioxidant activity and can be used in processing for health benefits. The flavonoids are major active nutraceutical ingredients from plant sources and are potent antioxidants and metal chelators. They also possess anti-inflammatory, antiallergic, hepatoprotective, antithrombotic, antiviral, and anticarcinogenic activities in human health (Sen and Mandal 2017).

5.2 Sous-Vide *Processing*

It is an advanced method of cooking in which fresh food is vacuum sealed in heat-stable pouches or films, and then cooked to specific time-temperature combinations to achieve pasteurization effect. This process improves the sensory properties of the product (Schellekens and Martens 1992). Rapid chilling is followed immediately after cooking to prevent germination and growth of bacterial spores and then stored at refrigerated temperature and can be consumed after reheating. The *sous-vide* processing maintains the color and flavor profile, tenderness, and enhanced shelf-life by reducing oxidation. The anaerobic pathogenic bacteria like *Clostridium botulinum* are a risk for these products, and thermal processing can prevent this (Ravishankar 2016). This method maintains all the sensory quality of products as less heat treatment is applied. The safety of such products depends on the extent of cooking temperature, cooling time and temperature, and temperature of storage.

5.3 Infrared Heating

Infrared (IR) radiation is the part of the electromagnetic spectrum which lies between ultraviolet (UV) and microwave (MW) energy. The conventional cooking in ovens by hot air can cause surface desiccation, charring, impingement damage, and lower yields (Krishnamurthy et al. 2008). Thus infrared cooking can be used for processing of fish and meats and such problems can be prevented. This heating method can be used in many food processing operations such as drying, dehydration, pasteurization, sterilization, and other cooking applications, and for pathogen inactivation (Gani et al. 2018). This method provides a quick and uniform heating and no energy is lost to the surrounding medium. This heating method can also be used for surface pasteurization and for inactivating the pathogenic microorganisms.

5.4 High Pressure Processing (HPP)

In HPP technology, meat products are submerged in fluid in a pressure vessel and cooked by high pressure with lower temperature. It can be used for improving the safety and shelf-life of processed meat products. The integrity, freshness, and taste of meat and meat products are maintained in this process. It can eliminate contamination of *Salmonella*, *Listeria monocytogenes*, and other food-borne pathogens. This technology could prolong the shelf-life of meat products by inactivating vegetative microorganisms and enzymes with minimal impact on the sensory quality (Simonin et al. 2012). At present, high pressure technology is mainly used in improving meat quality such as tenderness, water- and fat-holding capacity, etc. (Sukmanov et al. 2019).

5.5 Pulsed Light Technology

Pulsed light (PL) is a nonthermal technology and is a promising minimal process to improve the microbial safety of treated foods. It is an effective process for surface decontamination of food (Zhou et al. 2010). In this process, pulses of electromagnetic radiation (light) cause microbial cell deterioration. These pulses inactivate the microorganisms at the surface level of food and the packaging material. This is widely used for commercial scale decontamination of packaging of meat and fish products (Elmnasser et al. 2007). The quality changes of meat due to this process depend on the type of meat product and PL dose applied. This process has a great potential for the decontamination of seafood products as it does not change any quality attributes of seafood.

5.6 Bioactive Peptides

Bioactive peptides are defined as food-derived components which exert a physiological effect to the consumers beyond the nutritional value. As meat and fish contain high-quality proteins and essential amino acids, the bioactive peptides can easily be derived (Lemes et al. 2016). In general, bioactive peptides usually contain 2–20 amino acid sequences, and their activities are based on the sequence of amino acids. These peptides can be used as nutraceuticals to improve human health and prevent disease. Bioactive peptides are biologically active regulators and widely used for the treatment of various diseases and disorders (Ryan et al. 2011). Meat and fish derived peptides exhibit antihypertensive effects along with antioxidant capabilities and other bioactivities such as antimicrobial and antiproliferative activities. However, very few food products containing meat or fish-derived bioactive peptides are available commercially. In fish processing, a great amount of trimmings including skin, bones, heads, and viscera are rich sources of bioactive compounds which can be converted into peptides (Ucak et al. 2021).

6 Conclusion

Meat is also a good source of physiological bioactive compounds. The additional heath beneficial functions of meat products will help to improve the image of meat sector and better fulfillment of needs of consumer. Health-conscious consumers are increasingly seeking functional foods in an effort to control their own health and wellbeing. Development of healthier meat and meat product is a useful approach for health benefits of consumers. But marketing these products and convincing the consumers is even more challenging to the meat industry. Marketing of value-added products is completely different from the traditional trade. It is dynamic, sensitive, complex, and very expensive since it requires the response from consumers' behavior. Marketing surveys, packaging, and advertising are a few of the very important areas, which ultimately determine the successful movement of the new meat or fish product which is nutritious and healthy.

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Chapter 16
Indian Fish as Bioindicator Species

Preeti Kumari and Subodh Kumar Maiti

Abstract India is the second largest fish producer in the world. This review takes into account the observations from the open literature about the metal (loid) concentrations of Indian freshwater and marine fish species. Metal (loid) concentrations in edible part (muscle) of Indian fish species were compared with the international standards, and the higher metal accumulating species were considered for bioindicator studies. The freshwater species *Aorichthys aor*, *Heteropneustes fossilis*, *Labeo rohita*, *Mastacembelus armatus*, and *Triplophysa kashmirensis* were regarded as bioindicator species for freshwater ecosystems of India. However, *Arius parkii*, *Cynoglossus* spp., *Gerres oyena*, *Lates calcarifer*, *Liza parsia*, *Mugil cephalus*, and *Nemipterus japonicus* were considered as bioindicators of Indian marine ecosystems.

Keywords India · Freshwater · Marine · Fish species · Bioindicator

1 Introduction

After the green revolution in India in the early 1960s, India is self-sufficient in terms of energy demand. However, a decline in the protein intake is observed, the reason for which may be promoting only cereals and neglecting other better protein-rich sources. According to the National Sample Survey Office (2014), by 2012, the average protein intake by rural India was 57 g/capita/day, which were about 3 gm/capita/day lower than in the 1990s. This has led India to host 37% of stunted, 21% of wasted, and 34% of underweight children (Rampal 2018). Hence, policymaker has shifted the goal of increasing the production of food grains towards nutrient-rich food. Fish are not only the major source of protein but also rich in essential elements, vitamins, and unsaturated fatty acids (Rajeshkumar and Li 2018). About 69% of Indians consume animal protein sources (Rampal 2018), and per capita

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_16

availability of fish is 9.8 kg (Saha and Paul 2000). India is the second-largest producer of fish in the world after China, producing 2 million metric tons from the inland fisheries sector (Biswas et al. 2018; Saha and Paul 2000). Hence, fish are important edible sources for Indians.

On the other hand, fish is also used for biomonitoring of aquatic system with respect to metal (loid)s. Metal (loid) pollution is a serious menace to the ecosystem due to its persistency, non-biodegradability, and bio-accumulative behavior (Begum et al. 2005). The sources of metal (loid) contamination are anthropogenic such as sewage drainage, clinical/hospital disposal, idol immersion, industrial discharge, etc. However, the source of metal (loid) contamination is somewhat natural also and may come from the forest fire, surface runoff, and atmospheric deposition. Various abiotic factors drive the metal (loid) exposure/accumulation process and mainly include oxygen, total hardness, pH, alkalinity, and temperature (Begum et al. 2005). Apart from the mentioned factors, metal (loid) accumulation in fish is also driven by length, weight, exposure duration, life cycle, life history, lipid content, and feeding behavior (Farkas et al. 2003). Fish occupy a higher position in the aquatic food chain; hence they can accumulate metal (loid)s from food, water, and sediment (Uysal et al. 2008). Consumption of metal (loid) exposed fish by the human can cause an adverse health effect on human beings. For an instant, kidney failure, liver disorder, heart disease, and even death are the major symptoms of metal (loid) exposure through ingestion of contaminated fish (El-Moselhy et al. 2014).

2 Factors Affecting Metal (Loid) Concentrations in Fish

There are two factors, exogenous and endogenous, that regulate the metal (loid) accumulation in fish. Exogenous factors include contamination gradients of water, sediment, and food (Jayaprakash et al. 2015), chemical form (Cunningham et al. 2019) and bioavailability (Laird and Chan 2013) of metal (loid)s, the severity of pollutants, the occurrence of other pollutants, temperature (Trevizani et al. 2019), salinity, pH, hardness, alkalinity, dissolved oxygen (Mehmood et al. 2019), habitat (Jiang et al. 2018; Yi et al. 2012), exposure duration (Vinodhini and Narayanan 2008), and seasonal variations (Giri and Singh 2015), while the endogenous factors include age, sex (Trevizani et al. 2019), body size (Batvari et al. 2008; Bhupander and Mukherjee 2011), feeding behavior (Carvalho et al. 2005), bioaccumulation capacity (Bhupander and Mukherjee 2011), and movement of species (Trevizani et al. 2019).

Concentration gradients of metal (loid)s in abiotic components affect the metal (loid) accumulation in fish and other aquatic organisms. Elevated concentration of metal (loid)s in the abiotic components (water and sediment) resulted in increased accumulation in fish tissue (Giri and Singh 2015; Jayaprakash et al. 2015). Recent studies show that calculation of metal (loid) accumulation of fish based on total metal (loid) concentrations may overestimate the result; hence bioavailable fraction is considered for metal (loid) accumulation (Cheng et al. 2013). Bioavailable fractions are the amount of metal (loid) intake that is absorbed during the process of digestion and conversion into metabolically active species (Cabañero et al. 2004). Generally, the bioavailable fraction of metal (loid)s is less than 100% in fish species (Amiard et al. 2008; Gu et al. 2018). Another exogenous factor is the affinity of metal (loid)s to replace the metabolically active species such as Ca^{2+} ATPase, the Na^{+}/Ca^{2+} exchanger, and Na^{+}/K^{+} ATPase. Some metal (loid)s such as Pb and Hg have a higher affinity to replace such metabolically active species and can be accumulated in fish organs even at low concentrations (Lee et al. 2019). Besides, certain physicochemical properties such as salinity, pH, hardness, alkalinity, and dissolved oxygen can potentially affect the bioaccumulation processes.

In the natural environment, binding of metal (loid)s with inorganic and organic ions is determined by the salinity of the water. For instance, the binding of Hg with chloride (Cl^{-}) ions may form $HgCl^{4-}$, $HgCl_3^{-}$, $HgCl_2$, and CH_3HgCl, depending on different salinity (Wang and Wang 2019). However, there are contradictions regarding the relationship between metal (loid) accumulation and salinity. Smylie et al. (2016) and Webb and Wood (2000) have reported the inverse relationship between metal (loid) accumulation in fish muscle and salinity, whereas Li et al. (2015) observed the strong positive relationship. Some authors also reported no significant relationship between salinity and metal (loid) accumulation in fish (Reinhart et al. 2018; Yang et al. 2011).

Similarly, the relationship between metal (loid) accumulation and dissolved organic matter are also contradictory. Some authors such as Yao et al. (2011) have reported positive, while others such as Pickhardt et al. (2006) have reported a negative association between dissolved organic matter and Hg accumulation in fish. Also, the accumulation of metal (loid)s is governed by pH. Qu et al. (2014) have reported that at low pH, the concentration of Zn decreases due to competition between H^{+} and Zn^{+2} for binding sites on surface receptors of fish tissue. In other words, the accumulation of Zn was restricted by the presence of hydrogen ions. However, Goel (2006) have stated that pH is inversely related to metal (loid) accumulation at the lower level. Still, at a high pH level, there was no significant relationship existed between them. In addition, some authors also suggested that hardness of water can alter the metal (loid) accumulation in fish. It is believed that metal (loid) accumulation is higher in soft water than in hard water (Saglam et al. 2013). Apart from these factors, exposure duration also plays a significant role in metal (loid) accumulation. Qu et al. (2014) observed that Cd concentrations steadily increase in gill, liver, and muscle of the fish *Carassius auratus* while increasing the exposure durations. Zn and Cd accumulation in the tissues of *Oreochromis niloticus* was increased with increasing exposure periods in all concentrations tested except in lower Zn concentration (Fırat et al. 2009).

Besides, some metal (loid)s such as Zn can also affect the distribution of other metal (loid)s by altering the metabolism of other elements. Qu et al. (2014) reported that Zn can decrease the Fe content but can potentially increase the Cu content in the gill and liver of *Oreochromis niloticus* after long exposure duration. In addition, temperature also affects the metal (loid) accumulation in fish organs. Nichols and Playle (2004) observed the higher accumulation of Ag in the gill and liver of rainbow trout at the temperature of 16 °C in comparison to lower the temperature of 4 °C. Guinot et al. (2012) kept the *Sparus aurata* species at 22 °C, 27 °C, and 30 °C to observe the effect of temperature on the bioaccumulation of Cd, Cu, Hg, Pb, and Fe. They also observed the general trend of increase in metal (loid) content in fish tissue. The increasing temperature may result into higher metabolic rate, alteration in membrane permeability, and change in metal (loid) ion exchange system.

Generally, accumulation rate varies for different metal (loid)s in fish species. Majority of the literature suggests the maximum accumulation of Zn, followed by Cu (Giri and Singh 2015; Tao et al. 2012; Yi et al. 2012) in fish species. However, some authors also resulted out the maximum accumulation of Cu in the fish species. These differences in results are due to the varying affinity of metal (loid)s towards different fish tissue, different uptake mechanism, different deposition, and excretion rates (Giri and Singh 2015). Morphological characteristics of fish such as length and body weight as well as age and sex are closely related to variations in metal (loid) accumulation (Nădejde et al. 2019). Farkas et al. (2003) studied the relationship between the metal (loid) accumulation (Cd, Cu, Hg, Pb, and Zn) in organs and size and sex of the fish *Abramis brama L.* They showed that metal (loid) concentrations are negatively associated with the size and sex of fish species. However, according to Kidd et al. (2003), for Hg concentration, a positive correlation existed with the body size due to the continuous exposure and slow depuration of Hg. In addition, Yi et al. (2012) also showed the positive correlation between metal (loid) concentration (Cd, Cr, Cu, Hg, Pb, and Zn) and body size of fish. On the contrary, some authors have also observed no significant correlation between metal (loid) concentration and body size (Ouédraogo and Amyot 2013).

Moreover, when sex is considered, the interrelation between metal (loid) concentration and sex is also contradictory. Mortazavi and Sharifian (2012) demonstrated that generally, female fish concentrate more metal (loid) (Cu, Zn, Mn, and Cd) in comparison to male fish. They suggested that higher metabolic activities in the female are the main cause of higher metal (loid) (Mn, Cd, Pb, Zn, Fe, and Cu) accumulation in females than in males. However, Elahi et al. (2012) and Bastos et al. (2016) strongly denied the significant correlation between fish sex and metal (loid) (Hg) accumulation.

Various fish species from a single aquatic system may accumulate a variable amount of metal (loid)s. The inter-species differences in metal (loid) accumulation pattern may be driven by different feeding behaviors. According to Ouédraogo and Amyot (2013), carnivorous fish accumulates more Hg and Se than that of omnivore and herbivore fish. Similarly, Yi et al. (2012) have concluded that carnivorous and euryphagous fish accumulate higher metal (loid) (Cd, Cr, Cu, Hg, Pb, and Zn) than that of herbivorous fish species, while Weber et al. (2013) suggested that detritivore fish species accumulate more metal (loid)s (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Zn, and Pb) in comparison to carnivorous fish. In addition, Liu et al. (2015) resulted out a higher concentration of Cr, Zn, and Pb in omnivorous fish and Cu and As in bottom feeder. However, some researchers stated that omnivorous fish might accumulate more metal (loid)s (Zn, Ni, Cr, Cu, Cd, and Pb) from the natural aquatic environment when compared with carnivorous fish (Yousafzai et al. 2010), whereas some researchers claim that there is no significant relationship between feeding behavior and metal (loid) accumulation (Liu et al. 2015).

Previous findings of many authors showed that metal (loid) exhibited variable affinity to various organs. Generally, the liver, kidney, and gill are the major metal (loid) accumulating organs in fish. Nair et al. (2006) observed that in a weakly polluted area, the major accumulation of Zn, Cd, Pb, and Mn was observed in the liver. In contrast, in a heavily polluted region, gill was the major metal (loid) accumulating organ. Majority of the research suggests that usually, metal (loid) accumulation is low in the fish muscle (Hosseini et al. 2013; Liu et al. 2015) which is generally considered for health risk evaluation due to its consumption preference.

3 Fish as Potential Bioindicators of Metal (Loid) Pollution

Rapid industrialization and agricultural growth have increased the metal (loid) pollution, which has significantly impacted the aquatic flora and fauna, including human (Yi et al. 2012). Metal (loid) forms a larger group of elements, some of which are essential, while others are non-essential or toxic elements. Essential elements such as Cu, Fe, Zn, and Se are necessary for human metabolism. In contrast, non-essential or toxic elements such as Cd, Cr, Ni, Hg, and Pb are highly toxic and carcinogenic even at lower concentrations (Adhikari et al. 2006; Agah et al. 2009; Ali et al. 2019). Fish have been extensively used as a potential bioindicator worldwide because of the following reasons:

(a) Fish shows variations in specific habitat requirement and habitat shift during its different life stages (e.g., larval and juvenile stage).
(b) Fish, being migratory, can experience different pollution status of any aquatic water body. Hence, the assessment of fish represents the average condition of the aquatic ecosystem (Tao et al. 2012).
(c) The comparatively long life span of fish enables it for the better accumulation of metal (loid)s and other elements.
(d) Fish occupy different trophic levels in the aquatic food chain. Hence, it can reflect the trophic condition of the ecosystem.
(e) Fish, being a source of proteins, lipids, and vitamins of higher biological value, is consumed worldwide. Hence, the use of fish in bioassessment enables the researcher to assess the possible health hazard due to its consumption (Carvalho et al. 2005).
(f) Less number of fish species enables ease during its identification in comparison to other organisms.

India is primarily a vegetarian country, but there are regional variations in the fish intake rate throughout the country (Bark 2016). Due to the rise in per capita income and urbanization, the role of fish as an animal protein source has enormously increased (Barik 2017). These demands are higher in the area located near the water bodies and active flood regions. Over some time, increased demand for fish encouraged the farmers for pisciculture activities, which resulted in the increased production of fish at the rate of 5.1% per annum (Kumar et al. 2005).

4 Purpose of This Review

The purpose of this literature review was to examine the studies on metal (loid) pollution in Indian fish over 11 years (2008–2019). Firstly, we selected studies carried out in the edible part (muscle) of Indian fish. Then, we collected data regarding metal (loid) concentrations in fish from open literature and observed the range of concentrations specific to different fish species. Then we compared the metal (loid) concentrations with the maximum permissible limits prescribed by international standards. In addition, we identified the fish species recommended for bioindicator of freshwater and marine ecosystems of India. To our best knowledge, this is the first effort to examine the range of metal (loid) concentrations in Indian fish muscle.

4.1 Data Collection and Processing

This study systematically reviews a host of studies related to metal (loid) pollution in fish from Indian aquatic ecosystems from 2008 to 2019. Seven metal (loid)s, namely, As, Cd, Cr, Cu, Hg, Pb, and Zn, are involved in this study, all of which are considered as the primary metal (loid) pollutants by USEPA. Various databases were searched for the study, including web of science, PubMed, Google scholar, etc. and data from more than 74 sites were collected and analyzed (Table 16.1). The selected sites represented the freshwater and marine ecosystems of India. Publications were selected from the major Indian rivers and coastal area of India. Then the data for each fish species were compiled using the scientific name, study area, and metal (loid) concentration in edible muscle in dry weight units for the average values.

Literature survey of more than 200 articles, related to metal (loid) contamination in fish species, showed that As, Cd, Cr, Cu, Hg, Pb, and Zn are the elements of toxicological importance. Most of the assessments were based on combined concentration in fish. The present study took into account the metal (loid) concentration on individual fish species of the freshwater and marine ecosystem. This study will help to identify the fish species, which is most appropriate as a bioindicator of the aquatic ecosystem.

Table 16.1 Summary of six metal (loid)s analyzed in Indian fish species

	Number of species	Number of studies	Average (mg/kg d.w.)	Maximum (mg/kg d.w.)	Minimum (mg/kg d.w.)
Freshwater species					
Cadmium	38	25	1.28	28.15	0.02
Chromium	42	26	2.51	20.3	0.02
Copper	43	27	6.47	67.18	0.08
Mercury	30	21	1.44	7.4	0.18
Lead	44	26	4.76	17.3	0.04
Zinc	49	27	32.28	186.19	0.12
Marine species					
Cadmium	58	51	0.73	5.47	0.01
Chromium	32	31	2.16	10.15	0.07
Copper	58	51	9.88	47.97	0.87
Mercury	38	34	0.5	2.93	0.01
Lead	56	50	2.69	19.96	0.01
Zinc	54	48	37.05	182.7	1.86

4.2 *Wet and Dry Weight Conversion*

The formula for converting dry weight to wet weight is as follows (Rahman et al. 2012):

$$C_w = C_D * \left(\frac{100 - \%M}{100}\right)$$

where C_W is the dry weight mass of fish tissue, C_D is the wet weight mass of fish tissue, and %M is the percentage of moisture content.

Theoretically, if we have 80% water in fish tissue, it means that in 1 kg of tissue we have 800 gm of water and 200 gm of solid mass. So if we have 0.4 μg/kg Hg concentration, it means that we have 0.4 μg metal (loid)s in 5 kg wet weight of tissue (since 1 kg of dry matter have 4 kg water, because the water content is 80%). So we should divide 0.4 μg to 5 for the calculated amount of having metal (loid) concentration in 1 kg wet weight. So in this case, 0.4 μg/kg dry weights would be equal to 0.08 μg/kg wet weight.

5 Metal (Loid) Concentration in Indian Fish Species

5.1 Cadmium

The cadmium concentrations in 22 freshwaters and 53 marine fish species of India are given in Table 16.2. Among freshwater fish species, *H. fossilis* seem to be highly accumulating. Cd concentration in *H. fossilis* was 28.15 mg/kg, which was higher than prescribed limits of USEPA (2000), FAO (1983), and EU (2001). However, for marine water, the Cd concentrations of *M. cephalus* were found higher. The Cd level in both species mentioned above was higher than the EU (2001) and FAO (1983). Furthermore, on comparing the data with the standards, it was observed that 62% of the freshwater and 45% of the marine species exceeded the limit (0.5 mg/kg d.w.) of EU (2001). Also, the comparison with FAO (1983) showed that 8% of the freshwater and the marine species exceeded the prescribed limit of 2.5 mg/kg. However, only 3% of freshwater species exhibited the exceeded value than USEPA (2000) standard of 4 mg/kg, while no marine Indian fish species exceeded the USEPA (2000) limit for Cd. Considerably higher Cd value was observed in fish species from may be because of different domestic, industrial, and agricultural runoff from various sources (Maurya and Malik 2016), while the higher Cd value in marine fish may be mainly due to sewage disposal into the Indian marine ecosystem (Rejomon et al. 2010).

Table 16.2 Top five Indian fish species that exhibited higher concentration for cadmium

	Concentration (mg/kg w.w)	States	References
Freshwater fish			
Heteropneustes fossilis	28.15	Uttar Pradesh	Maurya and Malik (2016)
Oreochromis niloticus	3.2	Uttar Pradesh	Tiwari et al. (2017)
Mugil cephalus	2.72	Tamil Nadu	Bhuyan and Anandhan (2018)
Cirrhinus mrigala	2.07–2.31	Maharashtra	Shaikh (2013)
Labeo rohita	1.03	Andhra Pradesh	Banavathu and Mude (2017)
Marine fish			
Mugil cephalus	5.47	Gujarat	Raval et al. (2017)
Nemipterus japonicas	5.365	Kerala and Karnataka	Rejomon et al. (2010)
Lates calcarifer	4.76	Kerala and Karnataka	Rejomon et al. (2010)
Rastrelliger kanagurta	4.145	Kerala and Karnataka	Rejomon et al. (2010)
Cyanoglossus macrostomus	3.54	Kerala and Karnataka	Rejomon et al. (2010)

5.2 Chromium

Usual Cr concentration in Indian freshwater and marine fish species are given in Table 16.3. Heavily Cr accumulating freshwater and marine species is *Heteropneustes fossilis* and *A. parkii*, respectively. Cr concentration in *H. fossilis* is four times higher than the limit (5 mg/kg d.w.) set by USEPA (2000) and EU (2001), while in *A. parkii*, the concentration is two times higher than the standard limits. Also, comparison with the data showed that only 10% of the freshwater and 22% of the marine species exceeded the prescribed limits. While considering the sites, it was observed that the Kali river is severely contaminated with Cr. The elevated Cr level is probably due to the effluent discharge from tannery industries and domestic application of the river water (Maurya and Malik 2016).

5.3 Copper

Data on copper concentrations in Indian fish species are given in Table 16.4. Among freshwater species, *Crassostrea madrasensis* is highly Cu accumulating species. However, *Arius parkii*, Cynoglossus sp., *Gerres oyena*, *Liza parsia*, and *Sillago*

Table 16.3 Top five Indian fish species that exhibited higher concentration for chromium

	Concentration (mg/kg w.w)	States	References
Freshwater fish			
Heteropneustes fossilis	20.3	Uttar Pradesh	Maurya and Malik (2016)
Hypophthalmichthys molitrix	17.634	Uttarakhand	Negi and Maurya (2015)
Labeo rohita	13.011	Uttarakhand	Negi and Maurya (2015)
Triplophysa kashmirensis	6.187	Kashmir	Rather et al. (2019)
Catla catla	5.175	Tamil Nadu	Dhanakumar et al. (2015)
Marine fish			
Arius parkii	10.185	Tamil Nadu	Jayaprakash et al. (2015)
Liza parsia	9.72	Tamil Nadu	Jayaprakash et al. (2015)
Gerres oyena	8.73	Tamil Nadu	Jayaprakash et al. (2015)
Oreochromis mossambicus	8.58	Tamil Nadu	Jayaprakash et al. (2015)
Etroplus suratensis	7.495	Tamil Nadu	Jayaprakash et al. (2015)

Table 16.4 Top five Indian fish species that exhibited higher concentration for copper

	Concentration (mg/kg w.w)	States	References
Freshwater fish			
Crassostrea madrasensis	67.18	Chennai	Priya et al. (2011)
Mastacembelus armatus	41.36	Uttar Pradesh	Javed and Usmani (2016)
Heteropneustes fossilis	29.2	Uttar Pradesh	Maurya and Malik (2016)
Hypophthalmichthys molitrix	24	Kolkata	Kumar et al. (2011)
Labeo bata	17.37	Jharkhand	Giri and Singh (2015)
Marine fish			
Cynoglossus sp.	47.97	West Bengal	De et al. (2010)
Gerres oyena	40.565	Tamil Nadu	Jayaprakash et al. (2015)
Arius parkii	40.259	Tamil Nadu	Jayaprakash et al. (2015)
Liza parsia	35.26	Tamil Nadu	Jayaprakash et al. (2015)
Sillago sihama	34.95	Tamil Nadu	Jayaprakash et al. (2015)

sihama are the marine species accumulating higher Cu. Elevated Cu level in aforementioned marine fishes may be attributed to industrial discharge from the thermal power plant, petrochemical, automobile, chemical, pulp and paper mill, leather, soap, vegetable oil, fertilizers, plants, and untreated sewage disposal into the aquatic bodies (De et al. 2010; Jayaprakash et al. 2015; Mohan et al. 2012). While comparing with the recommended level (5 mg/kg d.w.) set by EU (2001), it was observed that about 26% of freshwater and 35% of marine Indian species have higher values. Furthermore, none of the fish data showed Cu value higher than the prescribed limit (150 mg/kg d.w.) of FAO (1983). Higher Cu value in *M. armatus* is due to the discharge of untreated effluent from thermal power plant into the aquatic bodies (Javed and Usmani 2016).

5.4 *Mercury*

Common mercury concentrations in Indian fish species are given in Table 16.5. Maximum Hg accumulating freshwater and marine species are *Wallago attu* and *Mugil cephalus*, respectively. While comparing with the standard of EU (2001), 53% of the Indian freshwater species and 29% of Indian marine species exceeded the limit. In freshwater ecosystems, Hg pollution may be possibly due to burning of

Table 16.5 Top five Indian fish species that exhibited higher concentration for mercury

	Concentration (mg/kg w.w)	States	References
Freshwater fish			
Wallago Attu	7.4	West Bengal	Pal et al. (2012)
Oreochromis mossambicus	2.9	West Bengal	Bhattacharyya et al. (2010)
Rita rita	2.25	West Bengal	Pal et al. (2012)
Chitala chitala	2.25	West Bengal	Pal et al. (2012)
Cirrhinus mrigala	2.2	West Bengal	Bhattacharyya et al. (2010)
Marine fish			
Mugil cephalus	2.93	Kerala	Mohan et al. (2012)
Rastrelliger kanagurta	2.515	Mumbai	Deshpande et al. (2009)
Brama brama	1.46	Mumbai	Deshpande et al. (2009)
Eleutheronema tetradactylum	1.305	Mumbai	Deshpande et al. (2009)
Johnius elongatus	1.15	Mumbai	Velusamy et al. (2014)

fossil fuel, mining activities, and discharge from chlor alkali industries (Alloway 2013).

5.5 Lead

Usual lead concentration in freshwater and marine fish species were represented in Table 16.6. It was observed that among different freshwater species, *Aorichthys aor* have higher Pb levels. Spatially, the higher Pb concentration was observed maybe due to discharge from the wastewater treatment plant, mining activities, fertilizer erosion, and agricultural run-off (Aktar et al. 2011; Gupta et al. 2009). Among the marine species, *Cynoglossus* sp. showed higher Pb values. The higher Pb concentration in the Indian ecosystems may be attributed to urbanization: water sports activities, deforestation, cultivation, and farming activities (De et al. 2010; Jayaprakash et al. 2015). On comparing the data with international standards, it was observed that 44% of freshwater and 24% of marine species exceeded the limits of FAO (1983) (2.5 mg/kg d.w.) and EU (2001) (2.0 mg/kg d.w.).

Table 16.6 Top five Indian fish species that exhibited higher concentration for lead

	Concentration (mg/kg w.w)	States	References
Freshwater fish			
Aorichthys aor	15.6	Uttar Pradesh	Gupta et al. (2009)
Aorichthys seenghala	17.3	West Bengal	Aktar et al. (2011)
Channa marulius	15.9	West Bengal	Aktar et al. (2011)
Heteropneustes fossilis	14.1	Uttar Pradesh	Maurya and Malik (2016)
Labeo rohita	14.81	Uttarakhand	Negi and Maurya (2015)
Marine fish			
Cynoglossus sp.	19.96	West Bengal	De et al. (2010)
Glossogobius sp.	14.28	West Bengal	De et al. (2010)
Liza parsia	18.6	West Bengal	De et al. (2010)
Pampus argenteus	12.4	West Bengal	De et al. (2010)
Setipinna phasa	18.33	West Bengal	De et al. (2010)

Table 16.7 Top five Indian fish species that exhibited higher concentration for zinc

	Concentration (mg/kg w.w)	States	References
Freshwater fish			
Mastacembelus armatus	186.19	Uttar Pradesh	Javed and Usmani (2016)
Triplophysa kashmirensis	101.835	Kashmir	Rather et al. (2019)
Etroplus suratensis	76.07	Tamil Nadu	Dhanakumar et al. (2015)
Labeo calbasu	71.46	Jharkhand	Giri and Singh (2015)
Aorichthys aor	70.65	Uttar Pradesh	Gupta et al. (2009)
Marine fish			
Caranx melampygus	70	Kerala and Karnataka	Rejomon et al. (2010)
Lates calcarifer	81.8	Kerala and Karnataka	Rejomon et al. (2010)
Lutjanus ehrenbergii	182.7	Cochin, Kerala	Mohan et al. (2012)
Mugil cephalus	94.87	Gujarat	Raval et al. (2017)
Nemipterus japonicus	67.2	Kerala and Karnataka	Rejomon et al. (2010)

5.6 Zinc

The zinc concentration in Indian freshwater and marine fish species were shown in Table 16.7. Among freshwater species, Zn concentration was found maximum in species *Mastacembelus armatus* while among marine species, Zn was higher in *Lutjanus ehrenbergii*. On comparing the limit of 150 mg/kg d.w. set by FAO (1983), it was observed that only 2% of the freshwater and marine species exceeded the limit.

6 Discussion

6.1 Cadmium

The response of metal (loid)s in fish species depends on elimination, metabolic storage, and detoxification process (Kim et al. 2018). The fish body has several physiological mechanisms to prevent metal (loid) toxicity. Among them, metallothionein (MT) is the most common and ubiquitous metal (loid)-binding proteins with high cysteine (up to 33% of all residues) contents. MT is induced by metal (loid) exposure in the gill branchial epithelium. MT can potentially bind to metal (loid) ions to form complexes due to the presence of a large number of thiol groups, and hence can prevent the exposure of free Cd ion in the body (Dang et al. 2001; Karlsson-Norrgren and Runn 1985). However, an elevated Cd level is known to be released from phosphate fertilizer, electroplating, chemical, pigment, plastic, and cadmium plating-based industries (Alloway 2013; Goel 2006) and may significantly affect the physiology. In fish, Cd uptake from the external environment takes place in two sites, the gill and the intestine. Generally, Cd concentrations follow the pattern: intestine>liver>kidney>gill>muscle (Le Croizier et al. 2018). Gills perform vital physiological functions such as gaseous exchange, acid-base regulation, waste elimination, and osmoregulation (Dang et al. 2001; Saibu et al. 2018). Accumulation of Cd in the gills leads to morphological impairment of gills, which further disrupts the plasma ion homeostasis in fish (Dang et al. 2001). Through dietary intake, Cd accumulates in the digestive tract. In the intestine, Cd is absorbed with the help of membrane transporters. After the digestive tract, the Cd reaches the liver and enters into the blood circulation, then finally accumulates into the muscle tissue. In fish species, Cd significantly affects the metabolical and physiological activities. For instance, Cd intake disrupts homeostasis, ion regulation, endocrinological, histopathological, and immunological properties, which affect the growth and reproduction of fish (Junejo et al. 2019; Le Croizier et al. 2018). Also, in some fish species, reported biological half-life of Cd in the liver and kidney is more than 1 year, suggesting that Cd in fish species can surpass the excretion mechanisms (Le Croizier et al. 2018). In the current review, Cd concentration in omnivorous fish species is higher than the prescribed standard limits of EU (2001), USEPA (2000), and FAO (1983) suggesting that intake of omnivorous fish species may be subjected to human health risk for Indian people. Consuming such Cd contaminated fish may cause severe health-related issues such as renal dysfunction and cancer in human. Hence, further Cd monitoring is essential for the sites where phosphate fertilizer, electroplating, chemical, pigment, plastic and cadmium plating-based industries are present in India.

6.2 Chromium

Chromium is a trace element essential for living organisms and plays a key role in the nutritional and physiological activities of fish. In some fish species such as *Oncorhynchus mykiss*, Cr is known to increase growth and development (Li et al. 2018). The major source of Cr is the effluent from textile, mining, tanneries, electroplating, dyeing, printing, pharmaceuticals, stainless steel manufacturing, rubber manufacturing, ore reining, chemical and refractory processing, ferrochrome industry, cement manufacturing plant, automobile and leather tanneries, and chrome pigments (Bakshi and Panigrahi 2018; Mohamed et al. 2020). In the environment, Cr is present in divalent, trivalent, and hexavalent oxidation states, and the trivalent and the hexavalent states are stable states (Rowbotham et al. 2000). Trivalent Cr (Cr-III) is less permeable to the cellular membrane, is non-corrosive and less capable of biomagnifying in the trophical level. Also, Cr (III) plays an effective role in metabolic activities of glucose, lipids, and proteins (Bakshi and Panigrahi 2018). Cr (III) is the structural component of the glucose tolerance factor (GTF), which is capable of promoting the action of insulin. Also, Cr (III) in GTF acts as a cofactor for insulin for transporting glucose from the circulation into peripheral tissue (Li et al. 2018). Trivalent form of Cr is less toxic to the aquatic system, whereas hexavalent form (Cr-VI) is more bioavailable and hence highly toxic to fish (Sanyal et al. 2017). The uptake of dissolved Cr (VI) from the environment through the gill can cause impaired respiration and morphological damage of gills. After passing through gills, Cr (VI) can rapidly accumulate in the vital organs and results in cytotoxic and genotoxic effects on the liver, kidney, spleen, and gastrointestinal tract (Mohamed et al. 2020). Bakshi and Panigrahi (2018) have reported the pattern of Cr accumulation in the fish organ as gill>liver>skin>muscle. Within the cell, the Cr (VI) undergoes metabolic reduction and produces reactive oxygen species (ROS). The free ROS can produce a mutagenic effect by disrupting the DNA helix, which may lead to the death of the organism (Lunardelli et al. 2018). Acute exposure of Cr (VI) in fish brings behavioral, cytological, immunological, biochemical, and endocrinological deterioration. In contrast, the chronic exposure can result in physiological, hematological, histological, and morphological alteration in fish (Bakshi and Panigrahi 2018). In human, Cr exposure is carcinogenic and teratogenic (Alloway 2013). An oral dose of 2–5 g of Cr (VI) can lead to gastrointestinal bleeding, huge water loss, heart blockage, and even death, whereas 1–4 day exposure of less than 2 g of Cr (VI) can result in kidney and liver damage (Rowbotham et al. 2000). However, Costa and Klein (2006) reported that Cr (VI) could cause cancer of various organs in human because Cr (VI) is isostructural with sulfate and phosphate at favorable pH and can be carried out throughout the body including the brain.

In the current review, Cr content was found higher in omnivorous fish species from Indian freshwater and marine environment. In addition, only 10% and 22% of the freshwater and marine fish data was beyond the standard limits, suggesting that Cr pollution is least concerned in Indian aquatic systems. However, the sites receiving effluents from the various point and non-point sources of Cr, as mentioned earlier, should be carefully monitored.

6.3 Copper

Copper is an essential element for the aquatic organism and human and plays a key role in organism hemoglobin synthesis, hematopoiesis (Chen et al. 2020), bone formation (Johari et al. 2020), metabolic functions, cellular respiration, and cyto-biochemistry. Copper acts as catalytic cofactors for about 12 important proteins and 30 types of enzymes which are necessary for the survival of organisms (Monteiro et al. 2009). The major sources of Cu are agricultural run-off, mining waste (Padrilah et al. 2017), and the use of algaecides and molluscicides (Padrilah et al. 2017). Besides, copper is a highly toxic element because it is non-biodegradable once it begins cellular activities (Padrilah et al. 2017). In natural water, copper is found associated with inorganic ions or organic compounds; among them, copper sulfate ($CuSO_4$) is highly toxic to fish (Carvalho and Fernandes 2006). Within the cell, Cu can easily bind to the protein, and nucleic acid disrupting normal cytological activities and results in the transformation of Cu^{2+} and Cu^{1+} followed by the release of free radicals (Padrilah et al. 2017). The elevated level of Cu results in impairment in ionoregulatory homeostasis (Crémazy et al. 2016), oxidative response (Braz-Mota et al. 2018; Carvalho and Fernandes 2006; Padrilah et al. 2018), energy metabolism (Braz-Mota et al. 2018; Carvalho and Fernandes 2006), hepatic activities, immunology, cellular morphology and histology (Monteiro et al. 2009; Padrilah et al. 2018; Xavier et al. 2019), neurology (AnvariFar et al. 2018; Padrilah et al. 2017), and respiration (Grosell et al. 2007) of various organisms. Gill and kidney are the most sensitive organs to Cu induced stress. An elevated level of Cu in the aquatic environment can result into the disturbance in gill ionoregulatory function (Xavier et al. 2019), which produces an adverse effect on sodium-ion, chloride ion, and sometimes ammonia homeostasis (Crémazy et al. 2016). Elevate Cu is also known to affect the oxidative response in some fishes such as *Apistogramma agassizii* (Braz-Mota et al. 2018), which may be due to release of reactive oxygen species (ROS) during the detoxification and repair mechanisms of fish (Carvalho and Fernandes 2006). Cu is also known as the stress-causing agent that can potentially alter the biochemical function and cellular morphology (Xavier et al. 2019; Padrilah et al. 2018). In addition, some fish species such as *Paracheirodon axelrodi* showed energy metabolic effects after Cu exposure (Braz-Mota et al. 2018). Also, Carvalho and Fernandes (2006) stated that Cu exposure affects energy reserves and level of glycolytic and lipogenic enzymes in some fish species such as *Prochilodus lineatus*, *Ctenopharyngodon idella*, roach, *Rutilus rutilus*, and *Larimichthys croceus* (Carvalho and Fernandes 2006). Additionally, Cu has a strong tendency to affect the central nervous system (CNS) by restricting the activity of cholinesterase enzymes (e.g., acetylcholinesterase, butyrylcholinesterase, and propionylcholinesterase) and disrupting nerve transmission. The impaired CNS leads to paralysis and even death of the organism (Padrilah et al. 2017). Furthermore, Anvarifar et al. (2018) reported that the two fish species, viz., *Oreochromis mossambicus* and *Oreochromis niloticus*, higher Cu exposure can cause gill necrosis and affected the chloride cell of gills. Grosell et al. (2007) stated that high Cu concentration might also lead to mortality of fish due to disrupted respiration process.

In the current review, the omnivorous freshwater fish accumulated more Cu content. Also, among collected data, only two freshwater species, *C. madrasensis* and *M. armatus*, exceeded the value of 40 mg/kg, suggesting that these two species can be used as a potential bioindicator for the Indian freshwater ecosystem, while Cu content varies between 30 and 50 mg/kg in about 12% of the Indian marine species data, suggesting that the marine ecosystem is more polluted in terms of Cu. Hence, the sites receiving industrial source as well as domestic discharge effluent should be carefully monitored for Cu pollution.

6.4 Mercury

The major anthropogenic sources of Mercury are power plants, electricity generation unit, fossil fuel combustion, and coal-mediated industries (Okpala et al. 2018). In the environment, mercury exists in three chemical forms: elemental, inorganic, and organic forms. The elemental form of mercury (Hg^0) is rarely present in water as this form is highly volatile and less bioavailable. Inorganic mercury includes Hg^+ and Hg^{+2} compounds generally found in dental amalgams, fungicides, cosmetic products, paints, and some tattoo dyes (Esser 2016). Inorganic mercury is converted into organic forms (such as methylmercury, ethylmercury, and phenylmercury) by either photochemical reaction or by sulfate-reducing bacteria inhabiting sediment and gill and gut of fish (Okpala et al. 2018). Among the organic forms, methylmercury (MeHg) is highly toxic to the living organisms as it may accumulate in the higher trophic level through the process of bioaccumulation and biomagnifications (Eagles-Smith et al. 2016). The human population is susceptible to MeHg through the dietary intake of aquatic food like fish because MeHg is non-soluble and can surpass the body elimination processes (Okpala et al. 2018). In fish Hg, exposure can induce immunological disorder such as hematopoietic viability impairment, decreased leucopoiesis, osmoregulatory dysfunction, and thymocytes enrichment that may cause huge cell death (Okpala et al. 2018). Intake of Hg contaminated food by the human can severely affect their vital systems. Even low concentration of Hg exposure is associated with neurological (Ursinyova et al. 2019), immunological (Esser 2016), renal (Ursinyova et al. 2019), cardiovascular, developmental (Zheng et al. 2019), and reproductive abnormalities (Zahir et al. 2005). Hg can severely affect the development of fetuses, infants, and children through mother and may cause retarded developmental and learning abilities (Zheng et al. 2019). However, in adults, Hg exposure may result in lack of attention, loss of hearing and visual ability, increased fatigue, and memory loss (Zahir et al. 2005). In addition, an elevated level of Hg may also enhance plasma creatinine level and cause kidney dysfunction (Ursinyova et al. 2019). Also, Hg exposure affects the process of homeostasis in human and causes cardiovascular disorders (Okpala et al. 2018). Also, Zahir et al. (2005) stated that Hg intake could result in decreased fertility rate and the birth of abnormal individuals.

In the present review, the Hg concentrations in the freshwater ecosystem were generally less than 3 mg/kg. However, the concentrations were quite higher (7.4 mg/kg) in carnivorous fish, *W. attu*. Also, more than half of the species exceeded the standards. Among marine fish species, concentrations were generally less than 3 mg/kg, and *M. cephalus*, an omnivorous fish species, is highly metal (loid) accumulating species. These findings suggest that exposure of Hg is a serious concern in Indian aquatic systems. Hence, it is necessary to regularly monitor the sites near coal-fired plants, mines, and burning of fossil fuel area.

6.5 Lead

Lead is non-essential, versatile, subtle, and the most toxic element which has been used for more than 6000 years ago (Adiana et al. 2017) in the production of glass, paint, fuel derivatives, batteries, electronics, and beauty products (Matouke Matouke and Mustapha 2018). The possible Pb sources in the environments are lead smelter (Friesl-Hanl et al. 2009), mining activities as well as paint, lead, metal (loid) electroplating, and plastic polymer industries (Omar et al. 2019). Apart from these, vehicular traffic (fuel combustion, dust from vehicular components, and road dust) and road making paints are also the major Pb source in the aquatic systems (Gioia et al. 2017). Like other metal (loid)s, Pb in fish is mainly derived from water and fish. The Pb toxicity effects on various systems and organs including renal, nervous, growth, reproduction, behavior, and ionic mechanism of fish (Araújo et al. 2016). In addition, dietary exposure of Pb in fish may alter the hematological parameters and plasma structure in certain fish species (Kim and Kang 2017). Within the cell, Pb compounds affect micronucleus, chromosomal abnormalities and DNA impairment due to abnormal elongation of tailed nucleoids in the erythrocytes of fish (Pham 2020). Dietary intake of fish is one of the major routes of Pb exposure in human. The Pb exposure results in the detrimental effect on the process of erythropoiesis, renal function, central nervous system, and cardiovascular activities (Papanikolaou et al. 2005). Due to the exposure, lead entered into the bloodstreams and transported to the various organs such as blood, soft tissue, and bones. In blood, about 99% of the absorbed Pb is accumulated in the erythrocytes, whereas only 1% of the Pb is found in the plasma or serum. The absorption of Pb in the blood circulation depends on the availability of Ca, Zn, and Fe ions. The Pb is transported to the vital organs such as the brain, lung, spleen, kidney, bones, and teeth through plasma. In addition, Pb is transferred to soft tissue and bones through the bloodstream, where it can stay up to 40 days and 30 years, respectively, in soft tissue and bones. The stored Pb is released into the blood during the bone metabolism activities and causes toxic effects. Kim and Kang (2017) reported that Pb might produce a deleterious effect on the blood system by disturbing the synthesis of hemoglobin and changing the erythrocyte structure, which leads to anemia and impaired hematocrit. Megasari et al. (2019) reported that Pb exposure could reduce the hemoglobin level in the blood, which can eventually disrupt the neurology and intellectuals. Long-term Pb exposure also results in memory loss (Omar et al. 2019), mental disorder (Adiana et al. 2017; Jia et al. 2017), lack of focusing ability, insomnia, confusion (Omar et al. 2019), and coma (Jia et al. 2017) in human. Furthermore, Pb exposure can increase the inflammatory cytokines and immune mediator's synthesis, which affects the immune system (Yin et al. 2018). In addition, Pb exposure may cause the failure of kidney, liver, heart, and muscles (Adiana et al. 2017; Jia et al. 2017). Pb also affects the growth, development, and reproduction (Matouke and Mustapha 2018). Like Hg, Pb can also surpass the placenta barriers, invade into the fetal bloodstream, and affect the brain development of the child (Tang et al. 2016).

In the current review, Pb concentration generally ranged between 0 and 15 mg/kg in case of both freshwater and marine ecosystem. 7 % of the total studied fish species exhibited higher Pb concentration (>15 mg/kg), were carnivores. This suggests that Pb concentrations are more likely to produce detrimental effect due to dietary intake of carnivorous fish species. Hence Pb pollution assessment is required, especially for the sites that receive effluent from Pb and fossil fuel-based industries. Also, sites located near the roads and receiving traffic loads should be monitored regularly.

6.6 Zinc

Zinc is an essential micronutrient that plays a key role in cell structure (Leitemperger et al. 2019; Zheng et al. 2017), enzymatic activities (Zheng et al. 2017), lipid, protein, and carbohydrate metabolism (Wu et al. 2016), cellular signal recognition (Pouil et al. 2017; Chen et al. 2018), transcriptional regulation (Chen et al. 2018), DNA and protein synthesis (Abdel-Tawwab et al. 2016; Chen et al. 2018), normal body growth (Abdel-Tawwab et al. 2016), and reproduction (Wu et al. 2016). Zn is a ubiquitous element, i.e., it cannot be depleted biologically and transform from one organic complex or oxidative state to another (Abdel-Tawwab et al. 2016). The major source of Zn in the aquatic environment is the corrosion of galvanized product, wearing of vehicle tires, urban runoff (McRae et al. 2016), soil erosion, pharmaceutical, and pesticides associated wastes (Abdel-Tawwab et al. 2016). In fish, Zn produces the detrimental effects on morphology, cellular respiration, cardiovascular activities, hematology, reproduction, growth, and development (Driessnack et al. 2017; Kumar et al. 2020; Kori-Siakpere and Ubogu 2008). In human, Zn exposure results in brain, gastrointestinal tract, prostrate, lymphocyte, and erythrocyte disorder as well as deficiency of Cu (Plum et al. 2010). Feng et al. (2002) reported that excess Zn in prostate cells results in apoptosis. In addition, Sharif et al. (2012) stated that excess Zn in the human body is associated with cytotoxicity and DNA damage event in human oral keratinocytes due to oral intake. Also, Zn exposure results in stomach cramps, nausea, epigastric pain, and vomiting (Plum et al. 2010). Long-term Zn exposure can affect cholesterol balance, diminish immune system function, and even cause infertility (Zhang et al. 2012).

In the current review, the carnivorous fish *Mastacembelus armatus* accumulated maximum Zn from the freshwater ecosystem. Also, 22% of freshwater species exhibited Zn concentration below 1 mg/kg, and the concentration of rest of the fish species ranged between 2 and 186 mg/kg. In the marine ecosystem, the Zn concentration ranged between 1 and 182 mg/kg in fish species; and omnivorous fish species (*Lutjanus ehrenbergii*) accumulated maximum Zn from the environment. The study suggests that Indian freshwater and marine ecosystems are least polluted with Zn. However, the sites located near the anthropogenic source of Zn should be monitored regularly.

7 Conclusion

We identified five freshwater (*Aorichthys aor*, *Heteropneustes fossilis*, *Labeo rohita*, *Mastacembelus armatus*, and *Triplophysa kashmirensis*) and seven marine species (*Arius parkii*, *Cynoglossus* spp., *Gerres oyena*, *Lates calcarifer*, *Liza parsia*, *Mugil cephalus*, and *Nemipterus japonicas*) that fulfill the requirement for bioindicator species (Table 16.8). Out of 12 selected fish species, most of them were the least concern based on the IUCN list. However, the status of *T. Kashmirensis* and *L. parsia* is not determined as per FishBase records; hence this issue should be considered before using them as bioindicators. The selection of 12 bioindicator species was based on the ability of fish to accumulate two or more studied metal (loid)s. Also, in this study, we considered metal (loid) concentrations in fish muscles because Indian

Table 16.8 Potential Indian bioindicator species, metal (loid) bioaccumulated and feeding habits

	Feeding Habit	Cd	Cr	Cu	Hg	Pb	Zn	References
Freshwater fish								
Aorichthys aor	Carnivorous					●	●	Gupta et al. (2009)
Heteropneustes fossilis	Omnivorous	●	●	●		●		Maurya and Malik (2016)
Labeo rohita	Omnivorous		●			●		Negi and Maurya (2015)
Mastacembelus armatus	Carnivorous			●			●	Javed and Usmani (2016)
Triplophysa kashmirensis	Omnivorous		●				●	Rather et al. (2019)
Marine fish								
Arius parkii	Omnivorous		●	●				Jayaprakash et al. (2015)
Cynoglossus sp.	Carnivorous			●		●		De et al. (2010)
Gerres oyena	Carnivorous		●	●				Jayaprakash et al. (2015)
Lates calcarifer	Omnivorous	●					●	Rejomon et al. (2010)
Liza parsia	Herbivorous		●	●				Jayaprakash et al. (2015)
Mugil cephalus	Omnivorous	●					●	Raval et al. (2017)
Nemipterus japonicus	Carnivorous	●					●	Rejomon et al. (2010)

people habitually consume muscles in their diet. Given our study limitations, it is quite necessary to consult local fisherman and administration to ensure that (1) the selected fish species fulfill the requirement for being a potential bioindicator for the metal (loid) concerned to the researchers and (2) fish population is not affected due to any research activities.

8 Ethical Statement

The authors declare that they are not involved in any conflicts of interest, including financial interests, relationships, and affiliations. The authors also declare that the manuscript has not been published in whole or in part elsewhere. Also, this manuscript is not currently being considered for publication in another journal. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Correction to: Characterization and Appraisal of Crop-Based Farming System for Sustainable Development of Agriculture

Vinay Prasad Mandal, Aishwarya, and Pavan Kumar

Correction to: Chapter 6 in: A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*, https://doi.org/10.1007/978-3-030-93258-9_6

The original version of the chapter was previously published with the incorrect spelling of the author's name and it has been now updated to "Aishwarya". This change is now included in the chapter and the book has been updated with the change.

The updated version of this chapter can be found at
https://doi.org/10.1007/978-3-030-93258-9_6

A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9_17

Epilogue

Pavan Kumar, Bambang Hendro Trisasongko, and Meenu Rani

Agriculture is undoubtedly one of the most important sectors for a country. Substantial efforts in research and policies have been made to make agricultural commodities available to the public. Uncounted challenges, however, are facing its sustainability and, in the longer term, affect the country's food security. Issues in crop production have long been known by researchers and policy makers. It appears that developments are still in progress through improving seed quality, soil resources, crop management, post-harvesting processing, and agricultural marketing for agriculture, with similar extent in animal husbandry and aquaculture. In recent decades, agriculture encounters agricultural land conversion, which often shifts the capability of a country to maintain its food security.

Current key challenges to agriculture also cover the impact of climate change. Uncertainties associated to climatic shift have made substantial re-thinking in agriculture systems. In this book, the editors attempt to promote strategies related to the adaptation, which in turn supposedly minimize the impact of climate change. Science, technologies, and adaptation strategies are the keys to climate change mitigation, which are the primary foci of this book.

Primer of the issue is presented in Kumar and Kumar, emphasizing the importance of designing future scenarios in which science, technology, and policy would contribute. Nutrient management as one of key successes in food production is presented. In Chap. 2, authors from African continent discuss an approach in managing

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A. Kumar et al. (eds.), *Agriculture, Livestock Production and Aquaculture*,
https://doi.org/10.1007/978-3-030-93258-9

nitrogen, which is one of the crucial elements for crop, to reduce its further impacts to the environment. Soil resources need to be well preserved to further ensure that their utilization would be sustained. Accumulation of unwanted soil properties would be detrimental to food production. While Pandey and Dubey present an interesting study in this book, public concern should also cover similar research agenda in a diverse landscape. Uprising concerns in changing climate have been approached through development of new cultivars, including rice as reported in Singh and Singh in this book, that are capable in handling scarcity of water or accumulating unwanted soil properties. This issue should be further promoted and disseminated. With this level of importance, governments should ensure that the information, or perhaps the products themselves, are open to public access.

Admittance for community to obtain common information about agricultural resources needs to be much improved. Critical information such as land suitability could be considered as a prerequisite for a better, environmentally sound farming system. As summarized by Hilda and Gweyi-Onyango, land suitability mapping could much be improved through the use of Geoinformation. When the information is ready, dissemination would then be implementable through Internet or map hard copies in communication lagged areas. This would allow stakeholders, especially farmers, gain enough information about the state of their land and options for sustainable use in agriculture, livestock production, or aquaculture. While land suitability is considerably a static data in nature, provision of dynamic information is also essential for farmers. This would involve complex operation, as partially studied by Shofiyati et al., including big data operation and frequent data analysis. While scientific communities have been advancing, wall-to-wall, operational systems are yet to be fully developed.

Efficient production line for agriculture needs to be well developed in developing countries. An approach presented in Sakha et al. attempts to identify actors responsible for production flow. While this research is localized in Africa, it is entirely interesting to see whether the approach is achievable in different regions. Strategies like value chain, as demonstrated in the case of pig by Mondal et al., are also essential for governments or regulating bodies to assist smallholder farmers gaining their aims, while maintaining the quality of their products for consumption (see a chapter of Haldar et al., for instance). The issues of diversification remain open in agriculture, animal husbandry, and aquaculture, as partially discussed in a chapter by Das and Mandal, and might involve in-depth studies in added values for natural products (see Sen et al. in this volume). It is believed that the solution would be excessively complex and should involve a greater stakeholder, including the consumers of the agricultural produces. In development perspective, it would correspondingly be interesting whether such adoption would lead to equitable achievement in different countries. Overall, central governments would likely be aware of the contribution of agricultural crop, livestock, and fisheries in strengthening local (especially rural) communities or the nation as a whole.

This book provides an insight about the role of farmers, as they are the strategic component in the agriculture systems. In many developing countries, part of the system involves women. While this issue is greatly raised by Sah et al., further exploration should investigate if this applies in other countries with similar condition. Exchanging experience will promote understanding options to a better balance between genders.

While case studies are presented in this book, or in previous publications, it appears that complexity of agriculture, animal husbandry, and aquaculture is far greater. Agricultural systems practiced by numerous communities are well established locally, and they are often suitable for climate adaptation. Promoting the case would be vital in the future agenda, in order to minimize the impact of climate change.

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