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Emerging Solutions in Sustainable Food and Nutrition Security

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Preface

Sustainable food and nutrition security is a critical issue that affects billions of people globally. While some regions have sufficient access to food and nutrition, suffering from obesity, diabetes, CVD, etc. as a result of overconsumption, others face significant challenges in obtaining the necessary nutrients to maintain their health and well-being. Yet, despite significant progress in reducing global poverty and hunger, the challenge of ensuring access to nutritious food remains a significant obstacle to achieving sustainable development and ending malnutrition in all its forms.

This book is intended to provide a comprehensive overview of the current issues and challenges of sustainable food and nutrition security, as well as practical solutions to address the challenges that we face in achieving a world where everyone has access to safe and nutritious food. It explores the complex interactions between food systems, nutrition, health, and the environment and discusses the possible interventions that can be implemented to improve food and nutrition security. The book draws on the latest research, policy analysis, and practical experience from around the world to provide a comprehensive and actionable roadmap for addressing the challenge of sustainable food and nutrition security. The book includes contributions from experts in the field of food and nutrition security, including academics, researchers, and scientists. Their insights provide a multidisciplinary perspective on the issue, drawing on knowledge from fields such as public health, agriculture, economics, and social sciences.

This book contains 15 chapters including the introductory chapter on the current situation of nutrition security and conceptual evolution of the knowledge of sustainable food and nutrition security and elaborates pertinent challenges in order to secure nutrition security. The remaining 14 chapters are divided into five parts, each of which presents a comprehensive overview of a specific issue related to food and nutrition security. Part I delves into the significance of traditional foods and biodiversity in achieving nutrition security, which also happens to be pressing sustainability challenge. Traditional food systems are often characterized by low carbon footprint and are, therefore, a viable solution to the challenge posed by food security. Chapter 2 provides an in-depth explanation of traditional foods; Chap. 3 explores Mongolia's traditional food culture; Chap. 4 provides a case study of the use of insects to address food security in Benin; Chap. 5 highlights the impact of the declining agrobiodiversity on dietary diversity and nutrition provisioning; and Chap. 6 explores the potential of sustainable aquaculture in ensuring food security.

Current agriculture practices have raised environmental concerns due to their negative impacts on soil, water, and air. Intensive agriculture practices focus more on the productivity or the yield of the crops, and sustainability of the environment receives very little attention. High inputs such as excessive use of synthetic fertilizers and pesticides could lead to soil degradation and water pollution and accelerate climate change. Pesticide residues in food are also a significant concern for food safety as exposure to pesticides has been linked to negative impact on human health. To address these concerns, sustainable agriculture and horticulture practices are being promoted. Part II of this book elaborates on these concerns and illustrates the current situation and focuses on possible solutions to the problems. Chapter 7 discusses carbon-sequestration and potential mitigation strategies for climate change, while Chap. 8 presents a scenario that considers food safety and pesticide residues.

Biotechnology offers a range of tools and techniques, including genetic engineering, plant tissue culture, gene editing, etc., to mention a few, that can be used to improve sustainable food and nutrition security. Therefore, Part III delves into the roles of biotechnology to secure sustainable food and nutrition security. Chapter 9 provides detailed information about the biotechnological methods employed for crop improvement while Chap. 10 illustrates how biotechnology helps to improve the quality of crops in terms of making nutrient-dense and environment-sustainable crops.

Currently hidden hunger, also known as micronutrient deficiency, is a significant concern in nutrition security, accounting for almost 2 billion people being globally affected from it. Part IV of the book deals with micronutrient concerns. Chapter 11 provides an update on the zinc research at present time and Chap. 12 discusses various interventions, including dietary diversification, food fortification, and nutrient supplementation to address hidden hunger.

Functional foods are foods that have been shown to provide health benefits beyond their basic nutritional value. On the other hand, traditional foods have long been used for their functional and medicinal properties in various cultures. Both functional foods and traditional foods play a major role in promoting health and preventing disease and are addressed in Part V. Chapter 13 illustrates the global perspective of functional food; Chap. 14 provides a case study of utilizing traditional foods as medicine by the Bhotiya tribe of the Indian Himalayan region and Chap. 15 draws attention to the philosophy of Ayurveda and traditional food to supplement nutrition.

While a book cannot offer a single solution to the complex challenges of sustainable food and nutrition security, it aims to stimulate discussion and provide a basis for further research and action. It is our hope that this book will contribute to a better understanding of the issues and inspire efforts to improve the food and nutrition security of people around the world.

We would like to thank all of the contributors to this book for their invaluable insights and expertise, as well as the editors and publishers who made this project

possible. We hope that this book will be a useful resource for students, researchers, policymakers, practitioners, and anyone interested in the critical issue of food and nutrition security.

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Chapter 1
Brief Account on the History and Conceptual Evolution of Nutrition Security: Past, Present and Future

Sampat Ghosh, Chuleui Jung, and Victor Benno Meyer-Rochow

1.1 Introduction

Looking at the world today from the perspective of problems associated with nutrition reveals two contradictory images: on the one hand, about 1.9 billion adult people are obese and on the other hand, 828 million people suffer from undernourishment or chronic hunger (WHO 2021; von Grebmer et al. 2022). Lack of food security inevitably leads to undernutrition, and overeating may not always ensure an uptake of essential nutrients. In both cases there are various physical problems like obesity, heart disease, joint pains and lethargy etc. are linked to excessive food intake. However, the results of low food intake are equally bad and various diseases are related to nutrient deficiencies. Therefore to link 'food security' with 'nutrition security' is more important than ever. The nutrient protection depends on the nutrient composition of the food. Needless to say, food resources have changed with the evolution of humans (Ghosh et al. 2018a). Agriculture which is the main component and source of food in modern human civilization was discovered only 10–12 thousand years ago (Harari 2015; Gowdy 2020). It is undeniable that as a result of the acquisition of knowledge, people have gradually modernized the agricultural systems, organized various technological and biotechnological advances for the

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purpose of greater productivity (known as The Green Revolution), and ensured food security for countless people; but at the same time, it had some unintended consequences (John and Babu 2021).

A realization that has emerged over time is the issue of the sustainability in connection with the condition of the environment. Over-emphasis on productivity places too much importance on only a few species and as a result thousands of useful species become extinct or nearly extinct. The excessive use of inputs such as fertilizers, inappropriate water, pesticides, landscaping, etc. exceeds the capacity of Nature; all of these encroachments have somehow accelerated the loss of biodiversity and supported climate change. Therefore, in parallel with the nutritional value of a food item, the process of food supply has also become a field of timely scientific attention and both 'nutrition security' and 'environment sustainability' are interconnected in any assessment of a food system. However, it took time to fully appreciate and understand the importance of the food nutrients. Here, first we shall focus on the historical background and how this realisation has developed.

1.2 Brief History of the Development of Knowledge About Nutrients

1.2.1 Protein and Amino Acids

Animal life does not exist without food and this was apparent ever since the first heterotrophic organisms came into existence. Humans are no exception. However, the idea and knowledge of nutrition being something one needs to care about did not happen suddenly. Small groups of prehistoric hunters and gatherers worried little about food. Hippocrates (Hippocrates: 460 BC–370 BC) in his time is supposed to have said 'Let thy food be thy medicine and medicine be thy food'. Although the statement may seem somewhat strange, it will be easier to understand it in the light of scientific progression. The idea of looking at food from the chemical point of view was initially not a practice at all. In 1785 Claude Louis Berthollet (1748–1822) observed that the gaseous substance produced from the decomposition of animal parts was actually ammonia, a gas composed of nitrogen and hydrogen. He published his observations at the French Academy of Sciences (Berthollet 1785 *cf.* Carpenter 2003a; Lemay and Oesper 1946). This was a very important discovery, because the results of multiple contemporary scientific experiments showed that nitrogen was present in the animal's body but not in sugar, starch, or fat, and hardly present in wheat (what we now know as gluten). In 1818, François Magendie (1783–1855) published his research data in a paper with the Academy of Sciences in France. He fed sugar to experimental dogs for about 2 weeks, which caused the dogs to lose weight and develop corneal ulcers, dying a month later. Magendie repeated the same experiment but this time he used olive oil, gum, and butter instead of sugar as food. Even if the diet changed, the consequences remained same, the dogs died. Magendie concluded that these foods used in his experiments did not provide all the nutrients to the dogs. Nitrogen was not present in any of the foods used in the experiments and their intake alone was not sufficient to sustain the life of the animals (in the case of dogs). Magendie concluded that the food items used in his experiments did not provide all the nutrients to the dogs (Semba 2012a, b). He realized the importance of *food diversity*. Nitrogen was not present in any of the foods used in his experiments and their intake alone was not sufficient to sustain the life of the animals (as in this case it was the dogs). So, it was found that *nitrogen was an essential element to support life*, but it was not known at first where and what the source of nitrogen in an animal was. At that time, Jean Baptiste Boussingault (Jean-Baptiste Joseph Dieudonńe Boussingault: 1802–1887), a French doctor and scientist, was researching the source of nitrogen-rich tissues in animals. He observed that legumes could use atmospheric nitrogen, but cereal plants could not; yet, the mechanism was unknown to him (Galloway et al. 2013). He concluded that the normal and regular animal feed supplied sufficient nitrogen to the animal, meeting the latter's daily physiological needs. What his observations further did was to refute the theory that the animal obtains its nitrogen from the environment. J.B. Dumas (Jean-Baptiste Dumas: 1800–1884), a fellow chemist of Boussingault, showed that the plant kingdom possesses members that can synthesize a variety of nitrogen-rich compounds, of which abundance is ultimately found in animals. He decided to go one step further to show that an animal is only able to oxidize the compounds it obtains from plants (Carpenter 2003a).

So far, we have only discussed the importance of nitrogen, but what until that period had been recognized as purely 'animal-matter' was albumin, fibrin, casein, and so on. Although each of them possesses different physical properties including solubility, each, however, also contains 16% nitrogen. In 1939, a Dutch scientist named Gerrit Mulder (Gerardus Johannes Mulder/Gerrit Jan Mulder: 1802–1880) stated that these substances had a common structure ('protein radicals') and were accompanied by elements of phosphorus and sulphur in varying proportions. This general structure is now known as 'protein' (based on Greek and meaning 'primary element of the animal kingdom'). Notably, each protein contains 16% nitrogen and the nitrogen-protein conversion factor (100/16 = 6.25) is still used to measure the amount of protein from nitrogen in an object/food (Salo-Väänänen and Koivistoinen 1996; Boisen et al. 1987). It was at that time that people first became aware of the importance of nitrogen and virtually immediately thereafter of *protein*. Today the nitrogen-protein conversion factor has been determined for a wide range of foods (Boisen et al. 1987; Sriperm et al. 2011).

Meanwhile, the German chemist Justus von Liebig (1803–1873) analyzed plant tissue and showed that there were 4 carbon atoms and 1 nitrogen and concluded that only plants can synthesize protein and animals can only add or subtract other elements to it. Again, Dumas and Cahours (Auguste André Thomas Cahours: 1813–1891) analyzed casein and serum albumin and found that the ratio of carbon to nitrogen was 4:1, although there was an exception in the case of proteins from legumes (extracted from pea and bean plants). In this case, the ratio of carbon and nitrogen was found to be 3.25:1. Legumes were thought to be highly nutritious at the time but were found not to convert to albumin with or without sulphur or phosphorus. Mulder's theory was criticized and since then the term 'protein' alone has been used instead of 'protein radical' (Carpenter 2003a, b).

Analyzing muscle tissues of the animal body, von Liebig found no fat or carbohydrates and assumed that the energy required for muscle contraction was produced by the breakdown of protein compounds, which was made possible by the synthesis and excretion of urea. Thus, protein was the only nutrient in the true sense (although this assumption will later be proven to be incorrect). However, the importance of protein was by then understood. Now it became imperative to understand its chemical composition. This realization came through some clever experiments. A controversy arose over gelatine in the early nineteenth century. Gelatine can be obtained by boiling animal bones and is a very nitrogen-rich substance. The discussion started whether gelatine could be used as a meat substitute in hospitals and could be expected to be a substitute for meat for poor people (Viel and Fournier 2006). Scientist Magendi was requested by the Academy of Sciences to research the subject, but the experimenter's observations went against conventional concept. It turned out that gelatine was not a complete food for dogs. But there was another important observation; even when all the water was removed, the gelatine meat substitute did not turn into a complete dog food (Carpenter 2003a). With that result a new chapter began, i.e. the discovery of the chemical structure of proteins. Magendi suggested a chemical analysis of the meat to find out what substances had leached into the water. The discovery of asparagine by Vauquelin (Louis Nicolas Vauquelin:1763–1829) and Robiquet (Pierre-Jean Robiquet:1780–1840) in 1806 occurred when concentrated asparagus plant juice was left to stand for some time. Despite being established as a protein hydrolysis product in 1899, cystine was reported in 1810 by Wollaston (William Hyde Wollaston: 1766–1828) while he encountered it in a type of urinary calculus. However, the era of modern protein chemistry could actually be dated back to the 1820s, when Henri Braconnot (Henri Braconnot:1780–1855) prepared glycine from gelatine by acid hydrolysis (Vickery and Schmidt 1931). After that it took little more than another 100 years period to discover other proteinogenic amino acids (Vickery and Schmidt 1931).

Protein content and amino acid composition, especially essential amino acids, are now an important factor in determining the quality of a food. Currently, the amount of essential amino acids in 1 g of ideal protein has been determined by FAO/WHO/UNU. In the introduction we mentioned that along with nutritional quality, food resources are also important for maintaining the balance of the environment. Foods such as meat or legumes (*viz.* soybeans, various types of pulses, etc.) are the main sources of protein. Meat consumption has increased more than ever before and continues to increase in parallel with economic development (Milford et al. 2019; Cheah et al. 2023). From the view of nutrition science, appropriate amounts of protein, bioavailability of various vitamins and mineral content in the meat consumption are important. However, from an environmental point of view, animal feed production requires a lot of agricultural land, a large amount of water, creates immense methane gas emissions, and is less efficient in converting livestock feed to meat, i.e. protein, etc. (deVries and de Boer 2010).

1.2.2 Fat and Fatty Acids

In the nineteenth century, two scientists, the physiologist Adolf Fick (Adolf Fick: 1829–1901) and the chemist Johannes Wislicenus (Johannes Wislicenus: 1835–1902) conducted a complex experiment, which was published in 1866. They decided to climb a mountain which had an inn at the summit to rest in. The time they began to climb the mountain, they had only consumed a very small amount of nitrogen-rich food. They collected all the urine during the climb for further analysis. They calculated that the amount of protein they excreted through the urine to find the amount of energy they expended in climbing, was greater than the energy (which they calculated from protein) obtained from the low-nitrogen diet (although not fully calculated at first, but later to be determined) (Carpenter 2003a). Now the question arose: what was the source of the energy? At this time Edward Frankland (1825–1899) of England was researching the matter of direct measurement of energy from food and urea and he showed that 1 g of protein provides 4.37 kilocalories of energy. The experiment of Fick and Wislicenus was now more easily understood. It was obvious that muscle protein was not the only source of energy and those carbohydrates and fats were also sources of energy (Carpenter 2003a).

Like proteins and carbohydrates, fat was not considered an essential nutrient until the first decade of the twentieth century, because it was believed to be easily synthesized in the body from carbohydrates (later researchers began to understand that carbohydrate was not an essential nutrient). Although partially true, this assumption was not entirely correct. In the early twentieth century, Thomas Burr Osborne (1859–1929) and Lafayette Benedict Mendel (1872–1935), not related to Gregor Johann Mendel, had studied the importance of fat. From their paper published in 1912, they initially concluded that 'true fat' (true fat meaning glycerides and their moieties) was not necessary for animal growth, because experimental rats fed a 'fat-free' (how that was achieved was not totally clear) diet grew normally. Later the two researchers realized that the 'fat-free' diet they fed the rats with was not extracted with alcohol, so it was not possible to get rid of all the essential fats and that that could have been the reason why the rats might have grown normally (Osborne et al. 1912, 1914a, b; Osborne and Mendel 1920). Elmer McCollum (1879–1967) conducted an experiment showing that rats became stunted on a fat-free (in this case properly fat-free) diet, but when fed eggs or ether extracts of butter then they regained growth. Wilhelm Stepp (1882–1964) proved by experiments that lipoid (lipoid) in egg yolk is an essential nutrient for rats. MacArthur and Luckett, conducting an experiment, came to almost the same conclusion, namely that lipoid extracted from egg yolk was essential for optimal growth in rats. In 1929, the husband and wife team of George Oswald and Mildred Burr (1896–1990) showed through experiments that giving rats food without fat caused them to suffer from various diseases (Burr and Burr 1929). If all fat could be synthesized from carbohydrates, this would not be the case. On the basis of their experiments it was concluded that fat was an essential nutrient (Burr and Burr 1930; Holman and George 1988). The Burrs later showed that adding small amounts of linoleic acid to the diet cured those diseases (Burr 1981; Spector and Kim 2015).

Fatty acids can mainly be divided into three categories from the viewpoint of saturation, namely saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids. In the case of polyunsaturation, the fatty acid is classified as omega-3 or omega-6 according to the position of the first unsaturated carbon from the omega end. The simplest omega-6 and omega-3 examples are linoleic acid and alpha-linolenic acid, respectively, both of which are essential for humans (Spector and Kim 2015).

1.2.3 Vitamins

Vitamins became known in the early twentieth century (Carpenter 2003c; Semba 2012a, b). Although several notable observations had been made a long time before that, a clear definition of a vitamin had been lacking. The observations of the Scottish doctor James Lind (1716–1794) in 1772 were particularly noteworthy in this regard. He noticed that during several long sea voyages citrus fruits prevented scurvy, but the specific substance (later known as vitamin C) responsible had not been discovered (the anti-scurvey factor, i.e. vitamin C or ascorbic acid, was isolated after a long time in 1921 and characterized in 1932). The Japanese naval officer and physician Kanehiro Takaki (Kanehiro Takaki: 1849–1920) observed in 1906 that if flour bread was fed to sailors instead of polished rice, it could prevent beriberi. At that time, too, the responsible compound (later known as vitamin B1 or thiamine and isolated by Casimir Funk (Kazimierz Funk 1884–1967) in 1911) was still unknown (Vorster 2009). In 1906 the English biochemist Frederick Gowland Hopkins (1861–1947) clearly stated his 'vitamin theory', for which he was awarded the Nobel Prize in Physiology and Medicine in 1929. However, it was understood through a number of significant experiments that there had to be other nutrients besides proteins, carbohydrates, fats and minerals that were essential for a healthy life but what these compounds were and in which foods they were contained, was not clearly known.

In the early nineteenth century, the 'germ theory' came into existence. Various microorganisms were found to be the causative agents of a range of diseases such as anthrax, malaria, cholera, leprosy, tuberculosis, diphtheria etc. However, no microorganism could be detected as a causative agent for diseases like pellagra, beriberi, rickets, scurvy etc. Therefore, an association between nutrient deficiency and diseases was slowly emerging backed up by observations and scientific experiments.

Nicolai I. Lunin (1853–1937) was a Russian scientist, who conducted experiments showing that experimental rats could survive on a suitable diet such as milk, but could not survive if they were given protein, carbohydrates, fat, salt and water instead of milk. Lunin concluded that there was something like an essential element in the milk that was helping the rodents to survive (Lunin 1881 *cf.* Semba 2012a, Semba 2012b). Carl A. Socin, working in Estonia, showed that the egg yolk contained some unknown substance that was essential for life and hypothesized that it had fat-like properties (Sochin 1891). During the siege of Paris in 1870–71, the city was cut off and as a result of that, the supply of milk and milk-based goods, was cut off. Unfortunately, many children died during this period due to the scarcity of milk. Attempts were made at that time to prepare and market milk substitutes, but their consumption as food failed to save children. The importance of this incident was immense and presumably the reason why milk became known as a balanced food. The German Wilhelm Stepp (1882–1964) conducted a series of important experiment; he mixed flour with milk to make flour paste and observed that it supported experimental rats to survive. But at a later stage when he extracted the flour mixture mixed with remnants of milk after alcohol and ether extraction, the rats were not able to stay alive for more than an extra 3 weeks. However, the addition of the re-extracted substances to the diet enabled the rats to live normal lives. Another test worth mentioning in this context is that which in 1912 Hopkins carried out. He found that rats fed with protein, starch, cane sugar, lard, and mineral nutrients did not grow well, but only a small amount of milk changed that. Hopkins referred to these unknown substances or substances as 'accessory factors' and Elmer McCollum and Margaret Davies (Marguerite Davis: 1897–1967) could show in their experiments that adding casein, lard, lactose, starch, and salt to an ether extract from butter or egg yolk only allowed test rats to grow properly. This observation was confirmed by Thomas Burr Osborne (1859–1929) and his colleague Lafayette Mendel (1872–1935). After they fed experimental rats a diet of protein, starch, lard, and 'protein-free' milk and then found that the rats only grew normally for 60 days but then died. But when they fed butter instead of lard (holding the rest of the diet constant), the rats grew and matured normally. Osborne and Mendel came to the conclusion that the butter contained some essential elements that were helping the mice to survive. After that it did not take long, for every vitamin to be extracted, analysed, molecularly structured, and chemically synthesized over the next few decades (Semba 2012b). Needless to say, people today are aware of the role of each vitamin compound. Vitamins are of immense importance in determining the quality of food. At present we divide vitamins into two categories from the perspective of their solubility. While vitamins A, D, E, and K are fat soluble, vitamins B, and C are water soluble. A look at many of the early scientific tests focused mainly on substances extracted from oil or fat.

1.3 Conceptual Evolution, Current Issues and Challenges

1.3.1 Food Security to Nutrition and Environment Security

The progress in the nutritional sciences continues. Clinical nutrition has links to metabolic diseases and pathophysiology, ketogenic therapy, nutraceuticals development, precision nutrition, bioactive compounds, nutrigenomics, nutrition and gut health, dietary habits and diseases etc. These are only a few of the recent topics of nutrition science that can be of use in the fight for better living conditions. However, on the basis of our current knowledge we understand the food as the main source of nutrients. Broadly, those nutrients which can be synthesized in sufficient required amounts are known as non-essential nutrients and those nutrients which cannot be synthesized by humans are known as essential nutrients. Those essential nutrients should be obtained from the diet. The recommended dietary allowances (RDA) for every essential nutrient have already been calculated and the nutritional compositions of our food items have been estimated. Therefore, food consumption should satisfy the requirement of all the essential nutrients to the body on a daily basis. Food security has been transformed into nutrition security. The amount of food alone is insufficient to maintain a person's good health, but it is important to have food that could supply all the nutrients at sufficient levels. As the population of the planet is still increasing and expected to reach ten billion before it stabilises or falls, it would be essential to increase the food production to feed the bigger population (Hickey et al. 2019). An intensification of agriculture and livestock maintenance has been introduced. Focussing on only a few high yield crop varieties, the increased amount of inputs and, advances in breeding technology undoubtedly produce more food, but at the same time the measures have become a serious burden to the environment. The intensive agricultural effort of today contributes significantly to environmental problems. The source of about 50% of the total amount of greenhouse gases is modern agriculture (Vergé et al. 2007). Therefore, it is important to ensure that the sustainability of the food production goes hand in hand with minimal environmental damage.

1.3.2 Traditional Foods and Dietary Diversity Is Essential to Achieve Nutrition Security

Dietary diversity is defined as the variety of foods and food groups consumed by an individual or population over a given period of time. A significant proportion of the diverse food resources available in our surrounding ecosystems has over time continually been neglected and replaced by 'improved' varieties of few crops and livestock (Ghosh et al. 2018b). As a result dietary diversity shrank which then consequently narrowed the base of food and nutrition security.

Despite the discovery of vitamins in the early twentieth century, the trend towards emphasising protein began around the mid-nineteenth century and persisted until the mid twentieth century or even longer. As a result of the overemphasis on protein, all food and nutrition issues were viewed in the light of protein, and even the food and health problems of the developing world were largely attributed to protein deficiency. It was believed that developing countries suffered not only from insufficient food, but also from insufficient protein. In Western civilizations, protein gained a special place and even with regard to social problems, especially in the colonies, one tended to look at the protein availability and no further. Local or ethnic food was considered 'uncivilised', 'inferior food'. Two British scientists John L. Gilks and John Boyd Orr, in a comparative study of the diet and health of the Kikuyu and Maasai tribes in Africa, concluded that the perceived poor health of the Kikuyu was due to their vegetarian diet and the lack of protein in it (Gilks and Orr 1927; Orr and Gilks 1931 *cf.* Nott 2019). In the 1930s, the British doctor Cecilia William attributed the disease kwashiorkor to a lack of protein, coining the term 'kwashiorkor'. In 1955 WHO, FAO, and UNICEF jointly established the Protein Advisory Group and several protein rich foods such as fish meal, fish powder, soy milk, flour mixtures etc. were introduced to tackle the numerous health problems assumed to be related to malnutrition based on a lack of protein. Many of these projects were later dropped (Carpenter 1994). A high protein diet could not fix all the problems and ultimately failed to improve the nutritional status of the Third World countries' poorer inhabitants. The realisation that came out of the ill-conceived projects, which were meant to improve the people's health, was contradictory to what had earlier been thought about the importance of protein (Carpenter 1994). In 1971 a joint FAO/WHO expert committee on nutrition finally admitted that there had been "a tendency to overemphasize the importance of either protein or calorie deficiency separately, whereas in fact the two almost always occur together" (Ruxin 1996 *cf.* Kimura 2013).

Until the nineteenth century and the first half of the twentieth century, foods generally used to come from cultivated, semi-cultivated and wild (uncultivated) plants. Intensive livestock farming was in its beginning stage until then. The cultivated and semi-cultivated crops provided staples while the wild plants were the source of accessory foods and together they supplied the necessary nutrients. However, the emergence of cash crop economies, i.e. introducing exotic crops suitable for local environments, changed everything and encouraged farmers to grow food crops and livestock for the purpose of earning money. In the wake of this new economic thinking, forests were cleared and high yielding varieties were cultivated, while nutritious but low yielding crops were shunned. From the last half of the last century the ecosystems that had existed for centuries were modified and a range of indigenous foods disappeared (Frison et al. 2005). Transitioning food systems are characterized by a shift away from traditional foods to the globalized food systems (Vogliano et al. 2021). The trend to adopt the commercial farming practices had a negative effect on the cultivation of less yielding indigenous crops, foods and varieties, leading to a shrinkage of the gene pool of food plants and also contributing immensely to the non-availability of quality foods systems and to the nutritional deterioratin of local people.

The change is often linked with the elevated incidence of non-communicable diseases. Let us give an example to make it clear: The Pima Indians live in the Arizona region of America. Water shortages were frequent in the region, and therefore the government built a huge canal seemingly for the development and uplift of the region. Now the cultivation focused around for the abundance of water. The Pima Indian people used to live by eating the fruits of cactus and beans, but now the diet had begun to change. Their traditional food supply was replaced with materials such as wheat flour, sugar, bread, etc. with the result that some negative aspects became dominant (Brand et al. 1990; Schulz and Chaudhari 2015). Diseases appeared in people that had virtually been unknown and those who had never suffered from diabetes now did. It was noticed that their low glycaemic index food was replaced by high glycaemic food and as a result the diabetes disease became manifest. But does development actually have to be harmful? Of course not, but anything (here: food) has to be evaluated from different perspectives and in a scientific context rather than from just one angle. For example, if we look at the diet of the Baiga tribe of central India, we will see that they consume some millet-type foods locally known as Kodo, Kutki, etc., foods, which are far more nutrient dense than those of conventional cereals such as rice and wheat (Rao et al. 2016). Although at present these millets are gaining some new importance, for quite a while, however, they were ignored (Ravi et al. 2010). Another instance pertains to the consumption of insects as food, known as entomophagy. While certain indigenous communities in the north eastern, central and southern regions of India incorporate insects into their diet, and have acquired a significant body of traditional knowledge about their use as food and medicine (Chakravorty et al. 2011a, b, 2013; Vidhu and Evans 2015; Shantibala et al. 2012; Jena et al. 2020; Mozhui et al. 2021; Devi et al. 2022), the practice is diminishing, possibly as a result of dietary transition. As insects are valuable sources of nutrients, including protein and minerals (Chakravorty et al. 2011a, b, 2014, 2016; Rumpold and Schlüter 2013; Ghosh et al. 2016, 2017, 2020, 2021; Meyer-Rochow et al. 2021), the reduction in entomophagy could lead to a loss of nutrients in the diet. Similarly, despite the high nutritional value (Baghele et al. 2022) and use as traditional food and medicine by several ethnic communities of India (Baghele et al. 2021), edible snails also have not received significant attention and are in danger of being replaced by western food stuffs.

A diverse diet can help to ensure that individuals consume a range of essential nutrients that are required for optimal health. This is particularly important in populations in which certain sections of the population that are at risk of malnutrition or nutrient deficiencies. For example, in low-income countries, where access to a variety of foods may be limited, promoting dietary diversity can help to improve the nutritional status of vulnerable populations, including women and children.

1.3.3 Food Fortification and Bio-fortification as a Tool to Manage the Hidden Hunger

Micronutrient deficiencies, often known as hidden huger, afflict more than two billion people worldwide. This is a form of undernutrition that occurs when intake and absorption of micronutrients i.e. vitamins and minerals (vitamin A, zinc, iodine, iron etc.) are too low to sustain good health. As poor diet is the primary cause of the hidden hunger, commercial food fortification may be a potential tool to overcome the micronutrient deficiencies. Food fortification or enrichment is the process of adding certain key vitamins and minerals to the staple foods to improve their nutritional value, thereby addressing nutritional gaps in the population. Fortification has been incorporated as a national program in many countries (Darnton-Hill and Nalubola 2002; Sirohi et al. 2018). Iodization of salt, iron fortification of flour, vitamin A fortification of sugar and of oil are now mandatory steps in many countries to avoid micronutrient deficiency-related problems. Wheat flours with thiamin, riboflavin, niacin, folic acid; margarine with vitamin A and D: they are steps undertaken by many countries as part of national fortification projects (Kimura 2013).

Biofortification is a relatively new approach that involves breeding food crops, using conventional or transgenic methods to increase their micronutrient content. A few examples of biofortified crops include vitamin A fortified sweet potato, maize, cassava, rice (golden rice), iron fortified beans, pearl millet, zinc fortified rice and wheat etc. (Saltzman et al. 2013).

1.3.4 Ultra-processed Foods (UPF) Increases Health

Processing of foods has a long history in human civilization and is not at all novel in modern life. Basic and time-honoured food processing methods include sun drying, streaming, roasting, smoking, fermenting, pickling, salting, baking etc., all of which involving various chemical and enzymatic changes to the food materials. These basic processing methods increase palatability, digestibility, nutritional profile, shelf life etc. of the various food types. Archaeological and historical literature indicates that food processing and preservation techniques existed in most of the ancient civilizations such as Harappa, the Greek, Egyptian, and Roman cultures, to mention but a few. In nineteenth century two remarkable progresses were witnessed, *viz.* bottling by Nicolas Appert using heat, glass bottles, cork and wax; and pasteurization by scientist Louis Pasteur to avoid bacterial contamination in foods such as milk, juices, etc. During the first half of the twentieth century, in response to the malnutrition (even under-nutrition) in many parts of Europe, owing to world wars I and II, mass-scale production and processing had to take place. The processing involved mainly canning or bottling, protein-enrichment, the marketing of high calorie foods, vitamin-fortification, etc. In the latter part of the twentieth century food processing became more advanced and by that time a consumer society for processed foods had already been formed. Technological advances included freeze drying, spray drying, juice concentrate, using artificial sweeteners, addition of colouring agents, use of preservatives, etc. and ready-to-eat meals became available while pressure cookers and microwave ovens available since the latter part of the twentieth century reduced cooking times and improved nutrient preservation. Currently NOVA classifies foods into four groups: (1) unprocessed or minimally processed foods (MPF) – edible plants, animals, fungi without any process applied to natural foods (fresh fruits, vegetables, grains, legumes, meat, milk); (2) processed culinary ingredients (PCI) – substances extracted from MPF (fat, oil, sugar, starch) and nature (salt) and intended to cook MPF and not intended for consumption on their own; (3) processed food (PF) – industrial products made by adding PCI to MPF (canned vegetables in brine, fruits in syrup, cheese); (4) ultra-processed food (UPF) – 'formulations of ingredients, mostly of exclusive industrial use, that result from a series of industrial processes (hence "ultra-processed"), many requiring sophisticated equipment and technology' (e.g., sweet and savoury snacks, reconstituted meats, pizza dishes and confectionery, among others) (Monteiro et al. 2019;

Elizabeth et al. 2020).The increasing economic development, and higher reliance or dependence on ultra-processed foods (UPF) (Monteiro et al. 2010; Baker et al. 2020) is often characterized by being nutrient-poor and energy-dense, and that is one of the leading factors behind malnutrition. A recently conducted study by Moodie et al. (2021) projected that the sales volume of UPFs in middle-income-countries will reach equivalency with high-income countries by 2024. The study showed that the sales volume of ultra-processed beverages is significantly higher than in high-income countries; even the annual growth of UPF sales is higher in middle-income countries than in high-income countries (Moodie et al. 2021). The scale of dietary transition is still underway, especially in the highly populated middle-income countries of Asia, Africa, and Latin America (Baker et al. 2020; Elizabeth et al. 2020) and the intake of UPFs raises serious concerns for global health (Pagliai et al. 2021), linked with altering the lipoprotein profile of children (Rauber et al. 2015), an increase in cardiovascular diseases (Juul et al. 2021), obesity and related cardiometabolic functions (Poti et al. 2017). Besides, the processing also generates several compounds such as acrylamide etc., known to have toxic effect on human health (Pundhir et al. 2019).

1.3.5 Consumer Awareness, Policies as Drivers of Food Quality, Functional Food (Nutraceuticals) and Environment Security

The current era is the era of information and this has also been reflected in the food industry. Today the consumers are concerned about the products, in this case the foods, they are buying and consuming and therefore an increasing demand for transparency in food labelling and greater access to the related information has taken place. The required information about foodstuff includes ingredients, nutritional content, food safety, ethical considerations related to food production, places of the food's origin, means of transport, etc. This, in turn, drives the industry to innovate the range of products so that that can reach the concerned consumers. For instance, individuals with a gluten allergy require access to gluten-free bakery products. Similarly, those with lactose intolerance need a selection of dairy products that are lactose-free. Additionally, individuals with diabetes seek sugar-free foods that have the same taste as the original products. To promote consumer awareness in the food industry, government agencies and consumer advocacy groups have implemented various initiatives, such as food labelling regulations, nutritional labelling requirements, and food safety standards. This rising consumer awareness towards the nutritional and health benefits of foods and the potential benefits in terms of immunity development or prevention of diseases is a driving force for the global functional foods and nutraceutical market (Daliri and Lee 2015). The term "nutraceutical" was coined from "nutrition" and "pharmaceutical" in 1989 by Stephen DeFelice, founder and chairman of the Foundation for Innovation in Medicine (FIM), Cranford, NJ. DeFelice defined nutraceutical as, "a food (or part of a food) that provides medical or health benefits, including the prevention and/or treatment of a disease". When functional food aids in the prevention and/or treatment of disease(s) and/or disorder(s) other than anaemia, it is called a nutraceutical.

Currently the nutraceutical market is a multi-billion-dollar industry and is expected to grow rapidly over the next decade, especially post corona pandemic (Chopra et al. 2022; Banerjee Bhattacharya 2022). The United States is one of the largest consumers of nutraceutical with a value exceeding 95 billion USD; the Asia-Pacific nutraceutical market is anticipated to increase at a CAGR of 5.9% between 2016 and 2026 and is anticipated to have a market share of USD 5.04 billion by the end of 2026; Europe, the third largest nutraceutical market was valued around USD 79.7 billion in 2016; Latin America is considered the fourth largest market for nutraceuticals in the world, with Brazil and Argentina being the largest –and growing-markets in Latin America, with a projected market value of USD 19.4 billion by 2026 in Brazil (Chopra et al. 2022). Regulatory frameworks and policies concerning nutraceuticals have been developed in several countries such as the Therapeutics Goods Act 1989 by the Department of Health and Ageing in Australia, the Natural Health Product Regulations (2004) by Health Canada, governed by the Food and Drugs Authority and the Natural and Non-prescription Health Products Directorate (NNHPD) in Canada, European Food and Safety Authority (EFSA)Directive 2002/46/EC in the European Union, Food Safety and Standards Act (2006) in India, The Foods for Specified Health Use (FOSHU) regulatory process in Japan, ANVISA (Agencia Nacional de Vigilancia Sanitaria) in Brazil, INVIMA (The National Food and Drug Surveillance Institute) in Colombia, Dietary Supplement, Health and Education Act (DSHEA) of 1994 in the United States, to name but a few (Yang 2016; Santini et al. 2018; Chopra et al. 2022). A wide range of functional foods contain symbionts like probiotics and/or functional compounds like prebiotics, omega-3 fatty acids, omega-6 fatty acids, antioxidants etc.

Several attempts in terms of designing specific policies have in recent decades been taken in order to avoid the undesired outcomes of food consumptions (Cochrane Public Health Group et al. 2016; Pomeranz et al. 2018); however, not all are sustained. For example, Denmark introduced a fat tax on foods items containing more than 2.3% saturated fat in October 2011. It was expected that the rise in price would inhibit people to consume the foods with saturated fat and ultimately would have a positive impact on human health. However, the taxation policy was heavily criticized and abolished in November 2012 (https://www.bbc.com/news/world-europe-20280863). Kerala, an Indian state proposed a 14.5% fat tax (as a part of the 2016 budget) on junk food such as burgers, pizzas etc. served in branded restaurants (https://economictimes.indiatimes.com/news/politics-and-nation/in-a-first-kerala-imposes-14-5-fat-tax-on-junk-food/articleshow/53113799.cms). According to the WHO guidelines or recommendations, less than 10% of the daily energy intake should come from free sugar to prevent obesity. Over-consumption of sugar is a major contributor to obesity and diabetes. Imposing tax on the sweetened beverages or sugary drinks or soda drinks may have indirect positive impact on human health and several countries such as some states of Canada, Brunei, France, India, Malaysia etc. introduced a tax on these products. 'Will the higher taxes break the addiction of junk food?' is a valid question in today's world (Pomeranz et al. 2018). Recently Columbia's congress voted for imposing taxes on UPF and sugary drinks to control the obesity and related health problems (https://healthpolicy-watch.news/colombia-votes-to-tax-junk-food-and-sugary-drinks/). In South Africa the mean daily sugar intake from the taxed beverages fell after the introduction of taxes (https://healthpolicy-watch.news/taxing-sugary-drinks-is-a-win-for-health-and-government-revenue/).

1.3.6 Current Stand on Food and Nutrition Security and Future Challenges

The world is suffering from various forms of nutrition problems (undernutrition, hidden hunger, overweight) as we discussed earlier. Moreover, the global population is still growing and it is expected that the planet will be inhabited by almost ten billion people by 2050. This clearly means that then there should be enough food to feed the world's population, but to achieve food and nutrition security for the growing *global* population (while populations in Europe and many Asian countries are actually decreasing: Hideo 2020; Anonymous 2021) is a challenge. Hunger has a very strong relation with poverty. Millions of people are living below the poverty line and cannot afford a sufficient amount of nutritious food. Therefore the challenge is to achieve a sustainable agriculture that makes a significant contribution to the livelihood of many, by improving economic and social development and increasing the affordability of quality food. Food security stands on four pillars viz. (1) food availability – this refers to the physical access to foods either from one's own production or what is available at the market; (2) food access – which means the number of households that can afford the food available on a regular basis; (3) utilization – which includes the biological aspect of food security, while utilization of food means that an individual is sufficiently healthy to be able to absorb the nutrients from the food that is available and accessible; (4) stability –which refers to the temporal dimension of food security and often involves food prices and volatility. Food waste is another enormously important issue. Nearly one third of the total amount of food produced by humans is wasted annually. This accounts to almost 1.3 billion metric tonnes of food globally wasted, i.e. allowed to rot every year without being used in some way (https://www.ucdavis.edu/food/news/why-is-one-third-of-food-wasted-worldwide). The food waste in the high-income countries generally is mostly from the consumer terminal, i.e. the postharvest loss is due to inappropriate storage conditions allowing fungal attacks, etc., while, by contrast, in the low-middle-income countries the loss is incurred at the time of the harvest and due to attacks by insects, birds, rodents and other mammals removing or damaging the produce. Another concern, in this context, is aflatoxin (a family of mycotoxin) contamination which is responsible for some profound losses of food globally. The supply chain, especially storage and packaging technology, needs to be improved in order to avoid this kind of food waste due to mycotoxin contamination, pathogens and pests. Lastly, of significant concern is also the huge environmental impact that the current practice of agriculture management (crops as well as livestock) has. The development of an acceptable sustainable agriculture and food system would be a huge step forward in our quest to ensure that nutrition security and environmental sustainability are not just dreams for future generations, but represent achievable challenges for the society of today.

1.4 Conclusion

In conclusion, food and nutrition security has to be seen as one multifaceted issue that requires a comprehensive approach to address it effectively. Achieving food and nutrition security is not only a moral imperative but also critical for the social and economic development of the human population. It needs to reduce poverty, improve general health, and overall lead to a more equitable and balanced human society and environment.

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Part I
Traditional Foods and Biodiversity to Achieve Nutrition Security

Chapter 2
Traditional Foods and Foods with a Tradition: It's Not the Same

V. B. Meyer-Rochow

2.1 Introduction

2.1.1 Background

We are born into traditions; we are part of traditions, shaped by them and pass them on. The way we dress is based on traditions, the way we behave and talk is, and even how we select our preferences is largely the result of traditional beliefs and upbringing. It is therefore not at all surprising that traditions play also a decisive role in the kinds of foods and beverages that we prepare and enjoy. And yet, despite hundreds of articles, books and reports dealing with traditional foods and especially when we refer to certain typical dishes or single out especially popular recipes, to actually define what might be considered "traditional" or can be labelled a "national delicacy" or be referred to as "ethnic", is anything but easy. The concept of seeing something as "traditional", according to Rocillo-Aquino et al. (2021), is based mainly on the perspective of the European consumer. Take, for instance, the American "hamburger". Could there be anything more traditionally American than a "hamburger"? Perhaps the apple pie and roast turkey for Thanksgiving come to mind and would be some worthy contenders, too.

Therefore, let's stick with these three examples of American traditional foods for the moment and examine how they would hold up against the most widely accepted definition of a tradition, namely as a way of thinking, behaving or doing something that has been used by the people of a particular clan, tribe, community, ethnic group or region for a very long time. However, what counts as "a very long time"? How long ago was the first-ever hamburger 'created' and did that actually happen in the USA?

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2.1.2 Hamburgers, Apple Pies and Roast Turkey

The most commonly accepted origin of the American hamburger is that the habit of placing a beef meat patty between the two halves of a bisected bread roll stems from a practice that was common in the German port city of Hamburg. In the late nineteenth and early twentieth century this kind of ‘fast and easy food’ made it to the New World, where a certain Charlie Nagreen of Wisconsin (Cohler 2019) is credited with having “invented” the American version of it in 1885 (other claims, however, exist like that of Fletcher Davis, who is said to have come up with his “hamburger” in the 1880s in Texas: Cartwright 2009). Almost certainly, the American hamburgers’ origins are, what is even today known in Hamburg, as the “Rundstueck warm”. As early as 1869 restaurants in Hamburg and nearby pubs offered “Rundstueck warm” as a fast and nutritious snack, often to be consumed with a glass of beer. My own grandfather, born in the nineteenth century was an ardent fancier of the Rundstueck warm and I remember many a Saturday or Sunday stroll with him in the early 1950s that included a short break for a luncheon of “Rundstueck warm” at a small port restaurant in Hamburg.

So, after 150 years, taken from Hamburg to the USA, are we now correct to call this kind of fast food an “American traditional food”? How about the second proverbial American traditional food, the famous apple pie? According to K. Eschner (2017) “neither apples nor the pie originally came from America”. Apples (*Malus domestica*) are native to Asia and have only been in America for about as long as Europeans have been. The pie isn’t a uniquely American invention either, for varieties of such pies existed in England and the Netherlands (and possibly other countries as well) centuries before they first turned up in America.

And how about the Thanksgiving Turkey? Roasted turkey plus other components of the menu seem so totally American that even while far away from America in Antarctica, I was invited over from Scott Base to McMurdo by American colleagues to savour this most traditional of American foods. Of course, there is no record of whether the early settlers had celebrated Thanksgiving with roast turkey or had used some other wild fowl or perhaps had enjoyed venison or something totally different. What we do know for certain is that the turkey is a tasty bird, native to America and that it is frequently served with mashed potatoes and offered with cornbread dressing and green beans for Thanksgiving. There are dozens of slightly often regionally different recipes, some containing pumpkin, others highlighting the apple-walnut stuffing or the cranberry sauce, but nobody could argue that turkey, potato, corn bread, pumpkin and beans aren’t truly American: they are (Crosby 2003)! Yet, traditionally American natives and even the new immigrants would not have consumed as sumptuous a meal as that which the present-day “Thanksgiving Dinner” represents and it may therefore not be originally American in the sense of indigenous food, but would rather qualify as a food that *became* a tradition amongst immigrant Americans and settlers.

These three examples of American traditional foods were meant to make it abundantly clear that despite wonderful definitions of the words “tradition” and "traditional" it is not always easy to decide whether a dish actually deserves to be labelled traditional or perhaps had better be called "established, time-honoured, and popular" or simply "just very common". Whether we can assign a food to a particular ethnic group or call it a 'tribal food' or link it to a particular region is equally difficult and the Jamaican tradition of consuming "Ackee and saltfish, served with rice" shows that beautifully well.

2.1.3 Is "Ackee and Saltfish" a Traditional Food?

Let me explain what I mean: the present day inhabitants of the Caribbean island nation of Jamaica are to an overwhelming degree of West African ancestry, but sadly tribal affiliations to the country or specific region of origin are largely lost. Therefore we have problems to link the dish with a particular tribe or ethnic group (Sainsbury 2021). The ackee, an orange-coloured fruit of the ackee tree (*Blighia sapida*), stems from West Africa and was taken to the Caribbean from Africa; it is thus not a native to America. The saltfish, served with the ackee, is usually a kind of air-dried stock fish of the cod family (i.e., the Gadidae), imported from Norway, and the rice is basically of South and South East Asian origin. And yet the dish is generally described as a Jamaican traditional food, widely popular and loved by no other than the famous sprinter Usain Bolt. One could argue that in spite of the fact that none of the ingredients of the dish are from the Caribbean and that even the African ancestors of present day Jamaicans would not have known "Ackee and saltfish served with rice", it is the way Jamaicans combined the three ingredients, which turned the food into their traditional dish.

This leaves us a with dilemma, for I could have come up with dozens of more examples of foods that are commonly called "traditional", but which on closer inspection do not satisfy the definition of "traditional". In fact, any dish outside the Americas that contains potatoes could not really be "traditional" as potatoes were unknown in the Old World before Columbus introduced them to the Europeans (Crosby 2003). So-called traditional foods that are based on (or contain) rice like the *joulupuurot* (various kinds of Christmas rice puddings in Finland: Mansikkamäki 2017) served in countries that never cultivated or could grow rice would be in a similar category. Even to claim that the traditional food served in Asian countries always contains rice is problematic as there are differences not only between the kinds of rice, but also between the ways the rice is prepared, spiced and served in the various rice-producing countries. If neither the historical roots of a dish, its link to a specific tribe or ethnic group or the geographic region that the characteristic ingredients of the dish stem from allow us to term a food "traditional" in an unambiguous way, isn't there anything that unites traditional foods and vindicates the use of the term? Perhaps the next few examples leave no doubt about their "traditionality" and that there really are some truly traditional foods.

2.1.4 The Scottish "Haggis" and the "Bule-Bulak Oying" of the Adi People

Although many countries have produced similar dishes, albeit with different names, the "haggis" is generally accepted to be of Scottish origin (Lemm 2022). The main ingredients of it are a sheep's heart, liver and lungs. The normally easily perishable offal, prior to being quickly cooked inside an animal's stomach, is minced with onion, oatmeal, suet, a variety of spices and salt and then served with swedes and potatoes (the latter, of course, not native to Scotland but originally from the New World and widely grown in Scotland for more than 300 years). The Scottish haggis is not only considered to be a national dish of Scotland, it is popular with Scottish immigrants in the USA, Canada, Australia and New Zealand and rightfully called a "traditional food" in agreement with the definition for "tradition" given earlier.

Perhaps it is even more satisfying to refer to the *bule-bulak oying* dish of the North-East Indian Adi Tribals as a traditional food (Meyer-Rochow et al. 2015). Wild rats as a food item are popular in many parts of the world, but since time immemorial the Adi have been catching rats with ingeniously constructed traps and known to turn the prey into a delicious and nutritious dish. During the *unying-aran* hunting festival on March 7th each year, thousands of rats are consumed and the *bule-bulak oying*, containing the boiled rat's tail, legs, heart, liver, testes or foetuses and other inner organs, is the most highly appreciated rat meat dish known to the Adi and served as a stew with leafy vegetables and rice.

Quite apart from the fact that both contain innards of mammals and are being cooked dishes, the examples of the Scottish haggis and the *bule-bulak oying* rat dish also both meet the requirements of being termed traditional foods by having had a long history and by being restricted to a geographic region with links to a specific tribe or ethnic group. However, the two examples show us even more than that: just like food taboos can create a "feeling of belonging" and aid in the support of the cohesion of a group, helping the latter to maintain its identity in the face of others, traditional dishes, too, can invoke a sense of "us versus them" (Meyer-Rochow 2009). They strengthen the bond of connectedness, even amongst newcomers or immigrants that have adopted the local diet. If on top of that, meals in which the whole community becomes involved or partakes in, are commonly served during periodic local festivals or at recurring auspicious events, then this would further bolster their traditional aspect.

A further two examples to which the aspects of a connection with a particular population or culture and a link to an annual or seasonal event apply are the Chinese edible bird-nest soup (Marcone 2005) and the use of *urumiit* amongst inhabitants of the high Arctic in Greenland and northern Canada (Millman 2017). Although the edible bird-nests of swifts are a predominantly traditional (rare and expensive) health food of ethnic Chinese, consumed mainly as a special dish during the Lunar New Year celebration, the nests are actually harvested in a variety of South Asian countries and sent to Hong Kong or mainland China. On the other hand *urumiit* is a food item that is locally collected in winter and used exclusively by people of the High Arctic: it consists of the droppings of the snow ptarmigan (*Lagopus muta*).

2.1.5 Historically Traditional: Foods with a Tradition and Traditional Foods Are Not the Same

The few examples give above have hopefully convincingly demonstrated that despite some useful definitions of the words "tradition" and "traditional", it is anything but easy to categorize a food, a meal or a dish as "traditional". Can staples like rice, millet, corn or potatoes, can bread, cheese or fish be termed "traditional"? After all, within one and the same country, even neighbouring towns or villages often pride themselves in having "invented" traditional recipes that differ from those of their neighbours: there are hundreds of varieties of rice and potato dishes, of breads, cheeses and fish specialities and therefore one has to me more specific to simply call something "traditional". The vast amount of regional variations of *sambar, rasam and dhosa* in India come to mind, because even if they bear the same name, they may differ in the kinds and amounts of spices added to them. So, who can claim to be the traditional "inventor" of the food or dish and which version is the most traditional? It's often impossible to decide.

Furthermore, to discuss traditional foods is also not made any easier by the fact that "foods with a tradition" exist that need not at all be "traditional" or even popular in the sense of having a lot of fanciers and that foods also exist that historically used to be traditional but nowadays for a variety of reasons no longer are available or widely known. In the latter category we can find whale meat in Japan, cooked or roasted dog meet in Korea and the now illegal practice of consuming monkey brain in some parts of China as well as the once wide-spread use of sturgeons as a traditional food item in Europe.

Perhaps one of the best examples of a food item that has a long tradition but that cannot rightfully be referred to as a "traditional food" of one people or one region, is the so-called "hardtack" (Biggers 2022), also known as "the ship's or sea biscuit" (Moisan 2009). Made out of barley, rye, or bean flour, water and salt, hard tacks are a kind of cracker that store well and can be kept in dry conditions over a very long time. Hard tacks represent an emergency food with a long tradition as sustenance for sailors of may nations on extensive journeys or for soldiers in military campaigns with no easy or regular access to fresh food supplies. Hard tacks are a regular food item, but that kind of food can hardly be called "appreciated" or, to stress it again, be linked to the traditional food of a tribe, people or country and food that has its known roots in a particular region.

Not only solid food items, but beverages, too, exist which cannot be called "popular" or interpreted as being especially favoured, but which nonetheless represent brews with long traditions. Hot drinks not made with beans of *Coffea arabica,* but based on roasted and ground acorns or barley as a substitute for coffee, immediately come to mind. Such poor coffee substitutes, known in Germany by the unsavoury name of "*muckefuck*" (from the French *moka faux* = false mocha: Kirmse 2021; Anonymous 2022a), certainly have a long tradition, but they cannot be termed traditional beverages since they are prepared and consumed by people with different ethnic backgrounds in different regions during different times of emergencies when real coffee is hard to come by or too expensive to be obtained. Tradition dictates that one turns to the alternative when there is a shortage of the supply, but it would be hard to justify calling the temporary alternative a traditional drink. The question after all would be: a tradition of whom, restricted to which part of the world? And although chewing gum is not a food and is rarely swallowed, one could ask the same question: is chewing gum a tradition or is it a practice with a tradition? It does have a long tradition, since mastic gum of the mastic tree (*Pistacia lentiscus*) has already in the Antiquity served the inhabitants of Greece, Turkey, Syria and Lebanon as an early form of swallowable 'chewing gum' (Kristbergsson and Ötles 2016). Traditional foods and foods with a tradition are clearly not the same, but frequently are linked to medicinal uses (Meyer-Rochow 2017).

I have given in this introductory chapter only a few representative examples and am fully aware that hundreds more from all regions of the globe could have been given. I therefore encourage every reader to think of additional examples of so-called traditional foods that do not fit the mould or of foods that have long traditions but which nevertheless could not possibly be termed traditional foods. That traditional foods need not be common or wide-spread or even tasty or healthy, has already been made clear, but that there are reasons for their existence and that they are usually linked to a people or a particular region has to be accepted. This is why in the following I shall focus on questions related to the origins of the traditional foods and what maintains or sustains them. Although the categories that I shall discuss are overlapping, they do allow us to highlight and distinguish important differences between them.

2.2 Factors Involved for a Food to Become Labelled "Traditional"

2.2.1 Availability (Geographic Location and Region)

Before a particular food or dish can become a tradition, the basic food material, be that fruits or vegetables, spices or meats, has to be available. It not only has to be available, but there has to be enough of it so that a large proportion of the population has access to it. If something is exceedingly rare, albeit of exquisite taste and fragrance, it is not likely to ever become a traditional food of a people or a region, because only a small minority (and then perhaps only well-to-do people or those with 'connections') would be the ones to know about the food and have a chance to enjoy it. Availability of the food and access to it are therefore crucial.

Geographic location, climate and seasons are the main determinants as to what is available and can grow and thrive in a region. And although Polar inhabitants would have enjoyed sliced pineapple, sweet corn, pork, or tuna meat, they had in the past no way of knowing, let alone obtaining, such food stuffs. Coastal people have always made ample use of marine organisms such as bivalves, fish, and sea weed and although inhabitants of the interior of a country with no connection to the sea might also have enjoyed seafood, they would not have been able to include that in their food repertoire – until recently that is.

Owing to extensive trade relationships and food exchanges between countries and regions, often continents apart, and owing to the speed with which food items can nowadays be sent across different zones of the globe, traditional foods are under threat. Newly arriving foods, supported by cleaver marketing campaigns, are often seen as more attractive than "old-fashioned" traditional foods. On the other hand, international links and trade can also help expanding the knowledge and acceptance of traditional foods in other than their countries or regions of origin. This has been spectacularly successful in recent years with regard to the Japanese "sushi", the South American quinoa (*Chenopodium quinoa),* whose seeds but also whose young leaves are edible and nutritious, and the rooibos tea *(Aspalathus linearis)* from South Africa. There are, of course, numerous other foods originally typical (or traditional) for one region that have 'escaped' their confines and are now available virtually worldwide: kebabs, for example, originated in the kitchens of Persia and Anatolia (Marks 2010), but you can now enjoy them almost anywhere in the world; the pizza hails from Italy, but it is now equally at home in Seoul (South Korea), Cochabamba (Bolivia) or Kairo (Egypt) and the quintessential English "Fish'n Chips" is now so common and popular around the world that even a movie by the same title was made by a Cypriote film team in 2011 headed by Elias Demetriou.

Obviously, geographic location as a criterion for the traditionality of a food or dish has lost some of its importance, but that does not mean that we can forget about the connection between a food or dish and where in the world the latter first became a tradition. Food traditions are not easily being given up by people; people are conservative when it comes to food and pass on traditional recipes from one generation to another – even if the people were forced to leave their homeland and make a living elsewhere and could not exactly find the same ingredients they had earlier used. The traditional staple of Indians is '*dhal'*, but in South India it is sometimes left plain and often made into soup-consistency – called Sambar (with some veges). In North India, however, the '*dhal'* soups are much thicker and served with different spices. Another difference between North and South Indian dishes is that in the north wheat-based and in the south rice-based dishes dominate (Kishor 2011).

Karelians of Finnish origin in the Tver-region northwest of Moscow still search for and collect mushrooms in autumn just like their ancestors from Finnish Karelia have done (Härkönen 1998). If the species were not exactly the same, it did not matter, as long as they fitted into the traditional menu. If original food ingredients were indeed not available in the new environment, people did not usually give up on their traditional food or recipe, but adapted it to locally available material (Ternikar 2014). People of European and especially Dutch, German and British ancestry in Namibia and South Africa, whose traditional food included the herring, switched to the pilchard and other fish species as *Clupea harengus* does not occur in southern hemisphere oceans. If venison was no longer available in South Africa, for instance for the popular *braai* meal, one turned to the springbok (*Antidorcas marsupialis)* and if for rice lovers, rice was not available for traditional rice containing dishes, then millet, buckwheat and the increasingly popular quinoa could serve as replacements. Cooks the world over are masters in finding substitutes for ingredients or food items that are needed for certain dishes but are unavailable and Indian cuisine is replete with traditional food that lacks meat completely and is thus purely vegetarian (Anonymous 2022b).

2.2.2 *Availability (The Role of the Seasons and the Weather)*

Seasons and seasonality used to play a decisive role in traditional foods, because some plant species are only edible during particular times of the year, produce fruit only in certain months, are best harvested or collected over a clearly defined period of time and are of superior quality only after a particularly dry, or warm, or cold, or wet winter, depending on the species. Food ingredients that are obtainable only during a particular season are not restricted to temperate zones, but in the tropics can depend on dry and wet seasons, calm or windy weather. Such weather and climate related availabilities are known from all over the world and can involve fruits, vegetables, fish, eggs and various game animals (cf., Mexico: Acuña et al. 2011; Zaire/Congo: Pagezy 1975; Japan: Nonaka 2010; Southeast Asia: Yhoung-Aree and Viwatpanich 2005).

In the Moluccas, for example the island of Ceram that I visited in 1975, the local coastal population waits every year for the moonphase-dependant annual spawning migration of the *laor* annelid worms that the residents relish as a seasonal tradition and then collect during the months of March or April (Liline and Corebima 2017). In other parts of the world with access to tropical sandy beaches, locals used to know when to assemble there to collect turtle eggs. Similar seasonal collecting migrations have been reported from northern Australia where Aborigines visited the breeding grounds of geese during the time of egg-laying to gather the tasty and nutritious item for their own consumption (O'Day 1991; Blackburn 2018). In Finland edible freshwater crayfish, for example, for the traditional and popular crayfish parties, can legally be collected every year only between 21 July and 31 October, i.e., prior to the animal's spawning season.

Obviously most apparent in connection with traditional foods is the link between seasons and an abundance of a food item when we focus on edible insects. Insects are ectothermic animals and apart from a very few species in which individuals can raise their body temperature by muscle twitching (as in the honey bee and also the bumble bee) insects survive the cold season mostly as larvae, grubs, pupae or eggs. Collecting certain edible species and the availability of food insects in markets of Cameroon (Muafor et al. 2012) and, as reported by Mozhui et al. (2020) and Kiewhuo et al. (2022) for Nagaland or Arunachal Pradesh in India, are therefore seasonal events. A famous example is also that of the Australian Aborigines, who in search of the traditional sustenance known as the bogong moth (*Agrotis infusa),* used to undertake migrations during the summer months into the higher mountains of New South Wales (Australia) to collect huge amounts of aestivating (= summer-resting) insects (Cherry 1991). Traditionally the Aborigines then would have de-winged and pounded the moths into a pulp or cake, which when roasted over charcoal, represented a tasty and healthy insect-based meal that would have lasted for several weeks when preserved by smoking.

2.2.3 History, i.e., How Long a Food Has Been Used by a Tribe, Community, or Ethnic Group

It is easy to appreciate that the longer a particular food item has been part of a person's diet, the greater the chance that it acquires the status of a traditional food item. However, this need not be the case, for bread has been part of the diet of millions of people and so has been rice, millet, corn or even the potato (despite its arrival in Europe only about 500 years ago), but few people would list these staples as "traditional foods"; their uses are simply too widespread. On the other hand, bush meat may have an equally long or even longer tradition and can be said to be part of the traditional food intake of people in vast areas of tropical South and Central America, of sub-Saharan Africa and parts of Asia let alone Aboriginal Australia. What makes one a "traditional food" and the other a "regular" or "common" and thus not necessarily "traditional food"?

Once again, we have trouble to clearly explain why one food item is usually referred to as "traditional" (e.g., bush meat), while others like staples with an equally widespread use and similarly long history are not. Obviously, not only how long a food item has been part of a people's diet, but also how frequently it is being consumed by the people appears to be important. Foods can become temporarily very popular and may even be termed "traditional", but then fade away. That holds true for American "Spam-meat" (at least in some countries, where it became very popular and then lost much of its appeal); loach nabe (*dojou* in Japanese) and the Korean *mikkuragi* or loach soup (*chueotang*) are other examples. The latter two used to be widely popular when much of the population was rural, various food items were in short supply and food choice was limited. As the situation changed so did the attitude towards what used to be many of the traditional foods. Attitudinal changes can, of course, also affect the traditional post-meal habit, e.g., to end a meal with a cracker or a cheese, some sweet or a fruit, a smoke or a drink.

As a general rule, however, we can accept that the duration a food item has been part of the local diet does have an impact on its status as "traditional". Locusts, consumed already by Jews thousands of years ago as inferred to by passages in the bible (Bible, Leviticus Chpt. 11:21), and the consumption of insects as a form of nutrition by our primate ancestors, are good reasons to call edible insects a food category with an ancient tradition as a form of sustenance for primates (Rothman et al. 2014). Will they now become mainstream, perhaps in the form of cricket flour or mealworm powder as "traditional ingredients" of products from bakeries, or snacks available at super markets or meals offered by avant-garde restaurants? Time will tell, but the consumption of insects was certainly once widespread (Bergier

1941; Bodenheimer 1951) and saw resurgence in some parts of the world after it had been suggested that edible insects could help ease the problem of global food shortages and WHO and FAO were requested to support the idea (Meyer-Rochow 1975).

It is interesting in this context to note that the meat of kangaroos in Australia also had a tradition of thousands of years as a food item of the Australian Aborigines, but that over the past few decades, four species of large and widely abundant species of kangaroo recently became approved as legal food for Australians generally and not just for "the first Australians". The meat of four species of kangaroo (red kangaroo: *Macropus rufus*, western grey kangaroo: *Macropus fuliginosus*, eastern grey kangaroo: *Macropus giganteus*, and common wallaroo: *Macropus robustus*), is now available at supermarkets and urban butcher shops and popular with health conscious folk in Australia and elsewhere. Time will show whether the trend holds and whether in the future kangaroo meat can be termed a traditional food not just for Australian Aborigines, but Australians generally.

2.2.4 Social Status, Religion, Beliefs, and Special Days

It is well known that people of high standing like royalty, leaders, chiefs, land owners and others with power or influence can usually indulge in better and more nutritional food than "common people". In most cases that has to do with wealth and connections, but in some societies traditions dictate that special members of a community receive (or are withheld) food items that differ from those the more *common people* have access to. In societies with different castes or social strata and in ethnic groups in which men have more rights and a higher "status" than women, traditions often dictate that different foods are to be eaten by members of different castes and gender. Although this leads to inequalities between people of the same area, it also has the positive effect that it spreads the pressure on certain highly appreciated food sources and restricts certain foods to sections of the population.

Medieval royalty in Europe often feasted on rare and even exotic animals like peacock, wild boar, venison, etc. and a banquet for wealthy Romans would usually have contained some rodents such as dormice which were not only regarded as a delicacy in ancient Rome but were a status symbol. However, not just in ancient Rome and throughout Europe it was considered proper to show off one's wealth with the food one ate and others could not have, but innumerous reports also from African, American and Asian societies exist that show how certain dishes became associated with leading individuals of a society and then acquired "traditional food status". As an example the traditional banquets of the Romanov Tsars in Russia could include caviar, pheasant tongues, boiled bear paws or moose lips in sour cream and other items unimaginable as regular food items for the peasants of the country (Borowiecki 2012). Frequently the ruling class could violate against food taboos that their subjects had to observe, but that the opposite also existed shows an example from the northern part of the Melanesian island of Kiriwina, where traditionally chiefs and their family members were only allowed to consume fried or roasted things and never could partake in delicious boiled or stewed foods (Meyer-Rochow 2009).

As an afterthought it ought to be mentioned that traditional foods can also be associated with particular professions or activities. The traditional food intake of models, artists, truckers, bankers, soldiers, sailors, etc. is not exactly identical and a typical food of sailors in the Hamburg and Bremen area of Germany is, for example, the *Labskaus*, a culinary speciality based on salted meat or fish, potatoes, and onion (Dieck 2013). Some recipes put beetroot and pickled cucumber into it, while others have these ingredients as side dishes. Potatoes and salted meats, however, are standard fare and designed to make a less-than-fresh cut of meat not only more palatable, but to stretch the meat supply as well. That food became a tradition of especially seamen.

In most religions traditional foods and dishes play special roles as re-enforcers. Irrespective as to whether the traditions are based on proximate or ultimate causes, the traditions may be interpreted as demands by the gods (or their representatives and spokespeople on Earth) as a sign of "obedience" to help the community members feel united. Although more widely known for their food restrictions, i.e., food taboos, Jewish and Muslim traditional cuisines have much in common and as a rule of thumb most kosher foods (not containing alcohol) are also halal. Traditions have it that for the holy month of Ramadan, Muslims only consume nourishment between sunset and sunrise. Common during that time (Prakash 2022; Tamer 2022) are various kinds of biryani, flavoured rice stuffed vegetables such as zucchinis, eggplants, tomatoes, etc., which are generally called *mahshi,* couscous (semolina served with chicken meat, fish or vegetables) and soups containing chicken, lentils, vegetables, etc. It is common to break a fast with a glass of milk or fruit juice and the consumption of dates or nuts.

Traditional foods based on religious beliefs can indicate cultural affiliations even long after a religion has ceased to be practiced. A case in point are apple pieces served with honey that my grandfather used to prepare and then named "Virginia apple" or the *blintzes* (especially with raisins), which I loved as a child, and the "gefilte fish", which my secular grandmother used to prepare ever so often: all of these are traditional Jewish foods that in my case had been part of a totally secular household, but nonetheless corroborated a Jewish link. However, the most traditional food event in the life of a practicing Jew is the Passover (Gray 2022) with its ceremonial dishes of chicken soup or roast lamb now often served with rice, vegetables and mushrooms, as well as an almond or poppy seed sponge cake and, of course, the symbolic and most important Passover Seder, in which six traditional food items are arranged on a special plate (Trowbridge Filippone 2022). They represent: Herbs like horseradish and onion to symbolise the bitterness and hardship that ancient Hebrews had endured in Egypt; a mixture of grated apples, cinnamon, chopped nuts and sweet red wine to indicate that it was the mortar Hebrew slaves had to use to build structures in ancient Egypt; parsley or other green herbs to represent hope and renewal as well as springtime; a roasted shank bone of a lamb that is the only meat on a Seder plate, but is not consumed and can be replaced by beetroot for vegetarians; a roasted egg as a sign of mourning (traditionally eggs are also the first food served to mourners after a funeral). The well-known unleavened, dry, cracker-like "bread", known as *matzah*, of which three are part of the Seder, complete the traditional food.

Traditional foods abound in all religions and the Christian tradition to consume fish only on Fridays, especially during the weeks of lent before Easter, is widespread. Sacred Christian foods also include milk and honey as well as olives and Christmas is celebrated by Christians and sometimes even non-Christians as in Japan with a special dinner that includes a Christmas Ham, roast goose or turkey, a boiled Christmas carp or some other meat and some cake (as in Japan) or a plum pudding (originally a British tradition). The proverbial Easter eggs are a food tradition with pagan roots. A typical traditional Finnish dessert around Easter is known as "mämmi" (Kiialainen 2014) and consists of rye flour, powdered malted rye, seasoned salt and dried, powdered orange zest. The mixture is then left to increase in sweetness before baking in an oven at 125 °C (or according to different recipes at 150 °C or even 170 °C) for 2.5–3 hours and chilled for u to a few days thereafter before being served.

In India "Diwali" (the Festival of Lights) is celebrated to mark the day on which Lord Rama came back home after 14 years of exile and winning the battle over the demon king Ravana. in many regions of India the festival is also celebrated as 'Lakshmi Puja'. On that day, people light up their houses and on the ground in front of their houses display beautiful rangolis. Apart from traditional sweets (Sravya 2022) like *barfi, ladoos, rasgulla, halwa, jaggery,* etc., there are so many traditional foods in India connected with festivals that it is sheer impossible to mention them all and I only wish to single out some that I have enjoyed myself in India like *vegetable samosas, rice kheer* or the South Indian *idlees* (also spelt "*idlis*"), the latter I love with Japanese shouyu (fermented soy sauce). However, that is not the traditional way Indians eat their *idlees*.

In Finland Finns celebrate midsummer night (Anonymous 2015), i.e., the longest day of the year (locally known as *Juhannuspäivä*) with some alcohol (of course!) and a traditional menu of new potatoes boiled in salt water with dill and eaten with fresh butter, marinated herring or '*graavilohi*' (salt-cured salmon). In Japan the New Year is considered the most important holiday of the year. It is celebrated with a special traditional food known as *Osechi Ryori*, served in lacquered boxes (Ito 2022). The preserved dishes that make up the *Osechi Ryori* usually consist of black beans, omelette mashed sweet potatoes, dried fish and *kamaboko* (a sausage like soft fish meat-based food) A noodle soup known as Toshikoshi Soba is another traditional New Year's food in Japan and so are the bitter orange daidai, soft rice cakes known as mocha and grilled fish known as Yakizakana. Koreans celebrate the lunar New Year and then feats on to name but a few traditional dishes, rice cake soup, kimchi dumplings, Korean Jeon-pancake, stuffed mushrooms, fried zuchini and bulgogi (marinated beef). For New Year there may be more than just one kind of kimchi and for desert one can have sweet rice pieces with dried fruit and nuts. During the hottest days of the year known as *boknal* the traditional dish of some Koreans, who consume dog meat, is known as *boshintang* stew or soup (Podberscek 2009). The dog meat in it is supposed to have a cooling effect on the body, but there are attempts to find substitutes for the dog meat in the form of vegetables, cashew nuts and a variety of mushrooms as well as spices. Whether that will hasten the end of one traditional food and be the start of a new traditional dish remains to be seen.

2.2.5 *Connections to Commemorative Family Events (Weddings, Pregnancies, Births, Deaths, etc.)*

We have already seen that a variety of traditional foods are used by people in different parts of the world in connection with religious festivals and other auspicious days of the year. The festivities and the traditional meals associated with them were meant to reinforce the community feeling and to demonstrate that nobody was left out and the society acted as one body. However, when it comes to the individual family, there cannot be congruence between other families: after all, names, birth dates, wedding dates, days on which exams were passed (or failed), jobs were confirmed, prizes were won, deaths occurred, etc., vary between families of even the same clan, tribe or ethnic group. For families in order to celebrate or commemorate such days, often special banquets are arranged and traditional dishes are being prepared.

For weddings traditional foods served often have symbolic meaning (Diaz 2019), but on the whole must be popular and at the same time special to mark the event. Wedding cakes with fruit (just like cakes to celebrate birthdays) are popular at weddings generally and colourful small cakes representing husband and wife are usually enjoyed by wedding guests in Vietnam. In Germany the first course of the wedding menu is usually a soup, but in Italy sugar-coated almonds are usually given at weddings as they represent the bittersweet sides of a married life and in Japan fish roe, usually herring, is served alongside other dishes to symbolise fertility. In Russia amongst many other food items a traditional and beautifully decorated and always circular bread loaf known as the *karavay* is presented. It personifies fertility, male and female unity and ever-lasting love with decorations of a pair of swans, hearts, roses, grapes, the sun and the moon. A very similar traditional bread cake accompanies the wedding ceremony in Ukraine, but in India a simple honey and yoghurt mixture, known as *madhupak*, symbolises harmony and a long and sweet life together. In Thailand golden-coloured *foi thang* noodles made from egg yolk are meant indicate good health and prosperity. In Korea jujubes and chestnuts play an important role just like the kola nuts (Malvaceae) do in Nigeria. In Morocca lamb is roasted over a fire for the special occasion and in China at least one of the many wedding meal courses features the red Peking Duck as a symbol of happiness. On Bermuda bride and bridegroom are given different cakes: the female cake consist of three tiers and is covered with a silver lining whereas the male cake is one tier thick and covered with a gold lining for prosperity.

General advice as to what is a healthy diet during a pregnancy and which traditional foods are particularly wholesome, is given to expectant mothers all over the world in all societies. However, regarding traditional foods during pregnancy as well as after the birth of a newborn, far fewer foods exist that are recommended as good and nutritious for mother and child than foods that are said to be avoided (Meyer-Rochow 2009). Although the birth of a child is an event that is always celebrated and there are certainly some traditions that stipulate which foods or drinks are to be consumed to mark this event, it is also clear that a wide variety of foods and drinks may be used. In countries of the Levant, a rice pudding spiced with anise, caraway and cinnamon, often garnished with coconut flakes, almonds, walnuts, pine nuts and pistachios is served to celebrate the birth of a newborn and called *meghli* (Imam 2019), while in China the tradition is to mark the day with a red-dyed boiled egg. In Lithuania to celebrate the birth of a child, a father had to prepare mead (i.e., fermented honey drink) and keep it until the child's wedding, but generally fewer traditional foods are specified for the birth of an individual than at a person's death.

Although some mourners do not feel wanting to eat anything at all (Rhodes 2012), so-called comfort foods are a tradition in many countries and regions (O'Brien 2020). In the state of Utah funeral potatoes are a standard among Mormon mourners, but Halva (in India a confection that is enjoyed throughout the year) is strongly associated with times of mourning in Turkey, Armenia, Iran, and nearby countries. For Orthodox Christians in the Balkans wheat kernels represent life and death and a dish with wheat kernels mixed with raisins, cinnamon, anise, sesame and pomegranate seeds, nuts and honey for sweetness, shaped into a mound with some parsley on top to represent grass at the burial site. In Jamaica a goat soup made with a male goat's head, entrails and testicles in a broth of carrots, potatoes and cooking bananas is prepared to highlight the connection between the beginning and the end of life. Amongst Jewish mourners, circular or 'roundish' food items like lentils, hard-boiled eggs or globular rolls, represent the cycle of life and for the Muslims of Kyrgyzstan the traditional bread (a mixture of flour, water, salt, sugar, butter and yeast sizzling in hot oil) honours and feeds not only the mourners, but also the deceased as the smoke from the frying pan carries the cook's prayers to heaven and appeases the spirits of the dead (O'Brien 2020).

Celebrations of a happy occasion, e.g., the win of a prize, success at a competition, a victory in a match or to mark the start of a new business venture, the first day of a new job, the return of a loved one after a long period of absence, etc., they all often involve champagne as a traditional and commemoratory drink. In many societies it is customary to consume wine with a meal and some famous traditional dishes actually require alcohol to be added to the food, e.g., coq-au-vin and the traditional plum pudding or need to be set alight as in the technique known as "flambé". No alcohol, of course, but candies and other tasty bits are traditionally given to the children on their first day at school in many European countries.

2.2.6 Health, the Food's Nutritional Value and Its Effect on the Environment

Traditionally the emphasis on healthy foods only played a major role in sickness and convalescence. A healthy individual thought less about whether a food item was beneficial and nutritious than whether it was tasty and available in sufficient amount. The notion that one not only can, but should select a food on the basis of its nutritional qualities and environmental impact is something relatively new and the result of scientific discoveries to which the public has been paying increasingly more attention recently. Although the (in the past not always correct) belief that certain foods had healing powers, increased or decreased a person's libido and could affect one's fortune was once widespread and still has some adherents, but attitudes have changed and unproven claims are being challenged.

It is now generally accepted that unpolished rice is more nutritious than white rice; that dark chocolate is better for the body than milk chocolate; that food rich in long-chain unsaturated fatty acids is healthier than food rich in saturated fats and that too much meat, especially that of the 'red kind', increases the risk of kidney and heart problems. The call has gone out to return to a healthy "traditional diet" (whatever that may be) and although traditional diets often are indeed far more balanced and nutritious than processed, preserved and packaged fast food items, not all traditional foods can be recommended (Povey et al. 1998; Sproesser et al. 2019). Proponents of the virtues of traditional foods frequently go overboard preaching the traditional food's superiority, which in some cases like many of the ayurvedic recipes may well be justified but in others may be outright dangerous: traditional English food has been termed unhealthy, the Korean *sannakji* tradition of eating live octopus has its problem if you do not swallow the wriggly animal quickly enough, and even the much loved Japanese miso soups are not without health risks (the latter because of the amount of salt in it as well as in other traditional Japanese dishes) and many Indian delicacies contain a lot of ghee and sweet ingredients which can be linked to obesity.

The traditional food of the Onabasulu in Papua Niugini, for instance, is based on the staple 'sago', the pounded pith of the sago palm. The way the sago is prepared by the locals removes almost all the vitamins, minerals, oil and protein from this food and what is left of the "traditional food" is a product of calorie-rich starch, but overall impoverished nutritional quality (Toyoda 2018). People's metabolisms vary and while an almost pure carbohydrate diet can be bad for some, a diet mainly based on meat can be equally bad for others. The recently much heralded "Palaeolithic diet" certainly kept Palaeolithic folk quite fit and healthy, but to recommend it as a panacea to prevent illnesses and ageing in modern societies generally is dangerously short-sighted as people and their metabolisms differ.

A case in point is that many East Asians are lactose-intolerant and a considerable percentage of the population in, for example, China, Thailand and Japan, also cannot break down ethanol-containing products due to a lack of the enzyme aldehyde dehydrogenase. Such metabolic differences between people of different regions are common and can sometimes explain traditional food preferences. The Tsimané, an Amerindian tribe of Bolivia (South America), the Hadza of northern Tanzania, and even many of the inhabitants of Okinawa (Japan) live on traditional diets dominated by carbohydrates, despite the availability of other food stuffs (Kraft et al. 2018; Eckelkamp 2021; Willcox et al. 2007). These people are known to be lean, fit and healthy into old age and also rarely suffer from heart diseases. But it does not follow that we should all switch to a carbohydrate-rich diet. For instance, the traditional food of the Polar Eskimos (who refer to themselves by their tribal names and are collectively known as "Inuit", which means "the real people": Freeman 2020) had almost no fruit, vegetables or carbohydrates at all in their diet and lived healthy lives on a protein and fat-rich food that was based on fish as well as the meat of warm-blooded vertebrates such as mammals and birds, the latter incidentally also a source of "*urumiit*" (https://en.wikipedia.org/wiki/Urumiit).

Although we have to be critical when it comes to accept what is promoted under the name of "traditional foods", there can be no doubt that much of the present-day fast food is junk food, bereft of health-promoting minerals, vitamins, poor in essential amino acids, but rich in saturated fats and unwanted carbohydrates such as sugar. It is noteworthy, however, that consumers in many countries are now willing to pay more for food that used to have a reputation as a staple for poor folk, but now is being promoted as healthier than that which used to be part of the diet of the upper classes: black or brown rye bread rather than the white, wheat-based bread comes to mind; traditional porridge has seen a 'come-back' and fresh vegetables as well as fermented foods have increased in popularity as an alternative to overcooked and over-sweetened food stuffs. Acorn jelly, once seen as a food of the poor in Korea, has now become a luxury item that is no longer cheap. The awareness that raising cattle for meat and dairy products is detrimental for the global climate and leads to a loss of natural habitats (Hedenus et al. 2014) has led to a dramatic worldwide increase in the number of vegetarians (who abstain from all kinds of meat but not milk products) and vegans (who avoid all products that have links to animals and therefore use oat, soybean or almond milk to replace traditional kinds of animal-based milk). Vegans cannot actually be called promoters of traditional foods, but have to be seen as the "avant-garde" in connection with what may well be one of the traditional foods of the future.

That nowadays environmental concerns, worries about biodiversity, neo-colonialism and exploitation of the world's disadvantaged as well as the inhumane and cruel treatment of animals used for slaughter affect the consumers' choices of what to buy and consume, has led to a shift in attitudes. Environmentally acceptable foods could be more expensive than traditional and cheaper mass-produced ones, but would still be preferred by some consumers, while other formerly highly appreciated traditional foods like shark fins or sea turtles would now be either boycotted or rejected. Foods grown or harvested with child labour are often avoided too, and the fear of contaminated food stuffs is the reason why so-called organically grown foods have become so popular. Some buyers even deliberately choose unwashed potatoes, carrots to which the dirt of the earth still sticks and lettuces or cabbages that show signs of having been attacked by caterpillars (indicating that they could not have been treated with insecticides).

2.2.7 Appeal of the Food, e.g., Visual Appearance and Odour

In this last section on what sustains traditional foods I want to highlight the appearance of a food item and the intentional or unintentional interpretation of a food item as traditionally acceptable. To illustrate what I mean let me start with a joke my grandfather used to tell. A Jew sees a beautiful red chunk of meat in a shop, enters the shop and, pointing to the chunk of the red meat, requests "2 kg of that wonderful beef over there, please", whereupon the shopkeeper replies "Sorry, Sir, but that is not beef; it is whale meet." Sadly, the Jew turns around uttering "Why did you have to tell me that; now I cannot eat that meat any more!" What this tells us is that the consumer finds "excuses" to accept a food item which is not actually acceptable as a traditional food, provided it *looks* acceptable and no questions are asked. Another example, I once had lunch with a devout Buddhist from Sri Lanka and was surprised that she had ordered a meat dish. When I politely remarked that I thought Buddhists would not eat meat, she replied that Buddhists were not supposed *to kill animals*, but that the meat of the animal on her plate had been killed by somebody else, and so she did not feel guilty consuming it.

It still did not fully convince me that she was doing the right thing, for Buddhists like Hindus do believe in reincarnation and when consuming meat they run the risk of consuming a reincarnated ancestor. In Japan even before the arrival of Buddhism, meat was not an essential part of the Japanese diet, but seafood was and when Buddhism took hold in Japan the concept of the transmigration of souls and the earlier taboo of eating meat from a bird or a mammal became linked. It did, however, not affect animals in the sea that had no legs. Anything that looked like a fish, whether it really was one or was not, could be eaten. It follows that dolphins and whales were therefore treated as fish and could be consumed. There are, of course, other examples and sometimes animals were interpreted as plants (e.g., sea cucumbers, which are holothurians and therefore relatives of starfish) and some plants or fungi were seen to resemble animals (e.g., the fungus *Hericium erinaceus* as a monkey brain: Anonymous 2022c).

Almost hilariously funny is the fact that barnacle geese were allowed to be eaten by Christians during the 40 days of the Pre-Easter period of lent, when the consumption of warm-blooded animals, i.e., birds and mammals was actually forbidden. Barnacle geese were the exception, because they were identified as a kind of marine fish that had taken to the sky! How did that strange belief take hold? There is a group of crustaceans, known as Cirripedia or "goose barnacles", which can be as large as an egg and which can usually be seen attached to floating debris in the sea. The goose barnacles resemble a bunch of tiny birds and with the arrival of barnacle geese from the Arctic in temperate Europe during winter, people assumed that the birds had emerged from their hiding places in the ocean. They were thus not classified as birds, but seen as a kind of fish that flew. This was very convenient as these animals tasted quite good and did not fall under the restriction not to eat birds during the weeks of lent. In fact as late as 1891 the Bishop of Ferns allowed "to eat the birds at table, the barnacle [geese] being more fish than fowl" (Kennedy 2021). Nowadays we treat this traditional use of a food item as history, but it does show how eager humans can be twisting observations to fit their expectations.

The acceptance of a food item and its elevation to the category of a traditional food obviously has many reasons and not just the visual appeal, but the odour, too, is important. For some the waft of grilled meat, boiled lobster or newly baked cakes can be irresistible and indicative of specific traditional dishes: when salmon is being smoked, for example, or meat is grilled at a barbecue, you can smell that from far away (and so can flies). But likes and dislikes of odours (just like visual allure) vary from person to person and although people usually agree that certain foods stink, some overcome their instinctive aversion and begin to associate the smell with the food's taste, which they admire and find exquisite. Among the cheeses, this holds true for the famously disgustingly smelly traditional Limburger, Tilsiter and French Epoisses cheese types and amongst the plants nothing beats the durian fruit. The smell of a ripe durian has been likened to the small of raw sewage, rotting flesh and smelly socks and although Singapore and Malaysia ban the fruit from public transport, it is considered a traditional delicacy.

The most traditional food of the Izu Islands of Japan (and I lived on one of them, namely Hachijojima, for 5 years) is a fermented fish of the horse mackerel family or the flying fish group. The fermentation of the fish causes it to become exceedingly smelly, hence its Japanese name of *kusaya* (stinky) and it is understood that if a family serves *kusaya* for dinner, then the whole street will know (the nearby residents will recognise the smell)! In some way *kusaya* is similar to the fermented Swedish herring known as Surströmming and the "Tuyo" and "Daing" of the Philippines (Anonymous 2022d), but despite the revolting smell of the fermented fish, enthusiasts appear to love the taste.

2.2.8 Afterthought: Traditional Foods and Drinks as a Result of Chance

There are several examples, and I have chosen two, that show how accidents can also have been the source of the serendipitous discovery of certain dishes or drinks, which then ultimately became widely popular if not "traditional". The first is a dessert known as "Kaiserschmarrn" in Bavaria, Austria and Slovenia and although numerous versions of its invention exist (Loxton 2018; Simonson 2020), it is agreed that it actually stems from a failed attempt to prepare a delicious dessert, which, however, the Austrian Emperor Franz-Joseph I. nevertheless enjoyed. That made the dessert so popular that it became a "classic" and a traditional food of the region.

The second example is the quintessential English breakfast tea, known as "black tea with milk and sugar". Although how and when exactly it was discovered that fresh green tea leaves can be dried and fermented, thereby changing their coloration, is not known, but an accidental discovery is often mentioned. Apparently, Chinese farmers that did not have sufficient time to process the fresh and green tea leaves left them in the sun. Dried out, they later fermented and changed into a red and ultimately black colour. Tea leaves of this kind, which became the preferred variety in Europe, were the origins of the English black breakfast tea (Banerjee 2020; Vicony Tea Directory 2016) and traditions like "tea breaks" and "afternoon teas" resulted from that.

Of course, we can go even further back in history and ask ourselves if it was perhaps by chance that people noticed that milk curdles when mixed with something sour and that soured milk need not be discarded, but can be consumed

(Subbaraman 2012). In the same vein, did ancient Chinese perhaps observe how some animals like, for instance, dogs bury some bones, or squirrels burying nuts and some birds covering their eggs with soil (Zheng et al. 2022), and then learn from them, so that they started to bury eggs (appropriately covered in an alkaline mixture of salt, tea, lime and ash) in the soil and recover them months later to enjoy their taste (Mari 2013)? We do not know how observations of what happens in Nature (one may think of the packaging of prey in layers of silk by orb web spiders to preserve such food for later) has expanded early humans' knowledge of food preservation, food preparation and food use. Perhaps the suggestion by Meyer-Rochow (2022) that molecularly engineered plant galls could be a future food item, harks back to observations that some plants produce fruit-like outgrowths that develop without the use of pollinators and seeds (Miller 2022)? In any case, traditional foods and foods with a tradition, customary foods, highly and widely-accepted foods, novel and popular foods: they all have a history of origin, a 'start' as to how they became what they are. To investigate this 'history' is what makes food studies so interesting and appealing.

2.3 Conclusion

To grow and survive, human beings all over the world need to eat. The food that humans ingest has to contain a balanced amount of carbohydrates, proteins, fats or oils and essential vitamins and minerals, all washed down with water or water-based potables. Yet, even though we all need the same constituents, foods used by humans vary extraordinarily around the world, as also the examples given in this chapter have shown. Traditions, availability, religious and beliefs, taste, directives what and what not to consume plus a multiplicity of other reasons that were explored in this chapter, play important roles and although based primarily on the selection of edible insects as food, much about the motivation behind the acceptance of a food item can be learnt from the detailed review by Ghosh et al. (2018).

One problem is to decide what justifiably can be called "a traditional food". Kristbergsson and Oliveira (2016) in their book on "Traditional foods: history, perception, processing" provide descriptions of what they identified as "traditional foods" and instructions on how to prepare them, but the foods they deal with could easily be termed "ethnic foods" or "foods characteristic of a certain region". If we included in the discussion on foods those that have a long traditional use such as hardtacks but are neither linked to a particular geographic region nor to a specific ethnic group, then to separate traditional from ethnic or widespread or popular foods becomes even more complicated.

Processes like controlled fermentation, preservation by smoking, drying, pickling and even methods of cooking such as grilling, frying, steaming etc. can vary regionally and lead to quite different and often highly distinct end products. Is there then still the need at all to call a food "traditional"? In some ways there isn't, but the alternatives are also unsatisfactory and therefore we are stuck with the term. However, it is essential that we define what exactly we mean by it when we use it.

Food varieties are becoming globally more and more available and less and less restricted to or associated with specific regions. New foods compete with established ones and old recipes are being modified; in some cases they experience a "renaissance" and in others they become outmoded and disappear altogether. A food item mentioned earlier, which used to have its fanciers worldwide (Bergier 1941; Bodenheimer 1951) with even Romans and Greek of the Antiquity relishing timber grubs, were certain types of insects. In Europe edible insects then disappeared from the menu for many centuries, but as of late have begun to experience some renewed interest and appreciation, driven perhaps by environmental concerns but no doubt also by 'neophilia' (an enthusiasm for something new and seemingly exotic). A similar comment could be made for some edible species of jellyfish, traditionally served in Japan as *chuka kurage* and in Korea as *haepari-naengchae*. These East Asian species, served as tasty salads, are in the process of becoming a newly accepted food item for people with western backgrounds, largely because of increasing jellyfish populations and dwindling oceanic fish stocks.

What is therefore important is to document the changes that are taking place in the food sector and to identify the origins of certain foods and recipes and to trace them back to their historical uses. It is through studies such as these that we learn why certain dishes "evolved" or "were invented" in some areas and not in others and what kinds of relationships of the dish or recipe existed with regard to the needs of the consumer. To make sure that specific dishes and food will not be forgotten, changed, renamed or falsely claimed, the European Union has introduced a classification for foods and wines (https://agriculture.ec.europa.eu/farming/geographical-indications-and-quality-schemes/geographical-indications-and-quality-schemes-explained_en#traditional-speciality-guaranteed): "Protected Designation of Origin" (PDO), "Protected Geographical Indication" (PGI) and "Traditional Specialities Guaranteed" (TSG). Some foods may also be included in the UNESCO "List of Intangible Cultural Heritage in Need of Urgent Safeguarding", so that their unique characteristics can be promoted and will not be lost.

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Chapter 3
Traditional Foods and Associated Indigenous Knowledge Systems and Its Role in Nutrition Security in Mongolia

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3.1 Introduction

Food and food consumption of Mongolians are part of their cultural heritage. The researchers noted that depending on the culture of making and consuming food and drinks, the religion, economy, customs, and natural and climatic features of any nation can be revealed and told. Our ancestors understood the laws of nature and prepared food rich in nutrients and easy to store in nomadic conditions. With the rapid increase in population and the shrinking space of nomadic civilizations, as well as the growing effect of manufacturing, the heritage culture of food and drink preparation is being developed and implemented in accordance with modern scientific and technical progress, hygiene and sanitation requirements. Producers, researchers and scientists are working together to make it more sophisticated and produce innovative products that combine tradition and innovation. Mongolian traditional foods and drinks have been compared to the history of their development, chemistry, function, importance, and use, based on the research done by food and food industry scientists.

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3.2 Mongolian Traditional Foods and Drinks and Their Origin and Development

3.2.1 Foods During Paleolithic Period

In ancient times, until the Paleolithic period or Old Stone Age, people used to collect their food from surrounding ecosystems by hunting and gathering. This method of food collection continued to improve over the centuries to the time when animals and plants could be domesticated and large amounts of food could be accumulated in a short period of time. If we look at the present time, Aborigines, Inuits, Pygmies, and Eskimos, the last remaining hunter-gatherers on the earth, are healthy people with sharp eyesight, strong slender bodies, and quick movements. They have relatively well-preserved traditions of direct consumption of natural foods or unmodified or primary consumption of nutrients.

Anthropologists from the University of Arkansas conducted a study that clarified the perception of the diet of Australopithecus, the great ancestor of humans. They had features such as the shape and size of the ape's teeth, enamel structure and wear, and the maxillofacial system. Compared to apes, the front teeth are relatively small, the molars are large and flat, and the tooth enamel has evolved to become thicker. It was discovered that the development of jaw and facial muscles in apes is better than that of humans (Pfeiffer 1985). These unique anatomical features suggest that the diet of Australopithecines was different from that of apes, which fed on soft things such as fruits, nuts, leaves, worms, and insects. According to the research, it is clear that Paleolithic people were omnivores and consumed foods of animal as well as plant origin.

Dietary patterns of humans and animals are preserved in their bones, so in the developed countries of the world, the study of the diet of ancient people is revealed by isotopic analysis of bones (Boutton et al. 1991). Human bones are made up of organic matter, water and minerals. Isotope analysis to determine the chemical composition of bone begins with the organic compound collagen protein, and collagen carbon atoms exist in two stable primary forms. The ratio of these in the bones can be determined by isotope-ratio-mass-spectrometry, and the index ranges from 0 to 30, and it is possible to determine the type of human food by this ratio. C13 is commonly found in edible plant species (C3 plants) of the continent. For example, if a person eats a lot of grain, the carbon isotope ratio of his bones should be high. This information allows us to clarify the food consumption of very ancient people. There is relatively little research on the history of the diet of the ancient people living in Mongolia, but the very ancient history of food consumption can be imagined from the tools used such as fossils and broken stones. At the beginning of the Paleolithic period, tools used for food harvest were of simple design and few types, but eventually they became sophisticated, and the range of activities such as hunting and gathering plants were expanded. Archeological evidence proves that the ancient people living in Mongolia during the Paleolithic period used stone, bone, and wood to make weapons for hunting animals, and harvest plant-based food. Although climates such as interglacial warming and dryness alternated, a cold and temperate climate prevailed; the necessity of consuming high-calorie foods was realized. From small animals such as marmots, squirrels, squirrels, birds and fish, to large animals such as lions, elephants, bison, deer, foxes, cormorants and lynxes, in order to use animal meat and fat as a reliable source of nutrients, are depicted in rock paintings from the Paleolithic, Mesolithic, and Neolithic periods. End of the Mesolithic and from the beginning of the Neolithic period, the domestication of animals and plants made it possible to plan food supply and consumption in advance, and became somewhat independent of nature. In this way, the food source of the people who lived in Mongolia very early on turned from wild animals and plants to domesticated animal products, and the history of the food consumption heritage of the Mongols, who developed the methods of processing meat, milk, and seeds (Batsukh et al. 2013).

In many countries of the world, plants were domesticated and agriculture was further developed, while in Mongolia, domestication of wild animals and animal husbandry received more attention (Tumurjav and Erdenetsogt, 1999; Tumurjav 2003; Miller et al. 2022). The era of food production began when skilled hunters and gatherers who were well adapted to the natural and climatic conditions of Mongolia, domesticated wild animals and plants to use meat, milk, cultivated seeds and grains. The domestication of wild foods led to the emergence of a wide variety of tools for food production, and as a result, fundamental changes in human culture began to take shape. It is believed that from this period, the inhabitants of Mongolia began to think of unique methods of food production and invent equipment. In this context, it is worth mentioning that Mongolians adapted some practices such as shifting with their herds seasonally, changing their pastures, using wild plants in a coordinated manner, which in turn helped them to avoid the hazards of zoonotic diseases those were common in middle east and south Asia.

3.2.2 Mesolithic and Neolithic Period

During the Mesolithic and Neolithic period people stepped from the era of food collection to the era of food production. By domesticating wild food, the development of human society was matured and the history of thousands of nations and tribes existing on the earth was formed. The concepts of settlement, population growth, migration, new technologies, and cultural relations are connected to the process of domestication of animals and plants. The Neolithic period brought a revolution in the history of human consumption of food.

Wild animals and plants have been domesticated in Mongolia since the Mesolithic period. Bone and dung remnants of wild animals from Paleolithic sites and Mesolithic rock paintings depict cattle pastoralism, while Neolithic archeological evidences are related to the cultivation of domesticated animals and plant species. As already stated earlier, unlike other contemporary civilizations in the Middle East, Southeast Asia, and South America where plants were domesticated and agriculture was developed, Mongolia developed domestication method of some wild animals. It is assumed that the Mongolian domesticated horses during the Neolithic period. One of the crops that may have been domesticated in Mongolia is the wheat which is able to grow in a cold and temperate climate. The seeds and roots of wild plants were collected and crushed, ground and soaked. Bones of wild animals and fishing tools are found in Neolithic sites. People in the lake region used spears, bows, and knives to catch fish for food.

3.2.3 Bronze and Iron Age

From the years when tools were made using stone, wood, and bone, it gradually shifted to the age of metal. The creation of the method of making tools from bronze brought a big change in the development of food production. The classic model of nomadic animal husbandry in the Mongolian steppes was formed during this period. At this time, the number of domesticated animals increased rapidly and spread over the steppes, forests, and Gobi deserts. In this way, the nomadic clans settled in the steppes of Eurasia and developed methods for milk and meat processing.

In countries with a warm and humid climate, such as Mesopotamia, Egypt, India, and China, ancient kingdoms began to form, while in the great part of Eurasia, the classic form of nomadic animal husbandry was developed and the art of producing food suitable for it was matured. Nomadic herding tribes lived in steppes and Gobi deserts during four seasons in long-distance and short-distance migrations. With the introduction of animal husbandry, Mongolians were able to live safely with a constant supply of food in all seasons of the year. With the increase in the number and type of domesticated animals, it was necessary to expand the amount of pastures for migration, to raise the species of animals under natural conditions, and to create breeds of animals that are resistant to them. Nomads made, bridle, pots, and food containers out of bronze and iron. Eating food in many ways has had a positive effect on human body development, aging and health. Pots, ladles, cups, knives and livestock equipment were made of metal. Bronze sickles, hoes, crowbars, hammers, and grain objects indicate that Mongolians plowed the land and planted crops in addition to herding horses and cattles. Thus, the main form of agriculture of people in the Bronze and Iron Age was animal husbandry, which was started since the Neolithic period, and the process of food production continued at the household level.

3.2.4 Period of Ancient States in Mongolia

Around the beginning of the present era, people who migrated according to the flow of water and grass, built portable homes with sheep felt and mountain wood in any season, invented food production technology based on the classical method of animal husbandry. The Huns, a nomadic tribe, settled in the grasslands from Lake Baikal to the Great Wall and the Khyangan Range to the Great Tarvagatai Mountains at the beginning of the present era. The nomadic tribes, freed from the control of the settled nations in the south, had a guaranteed and independent supply of food by herding livestocks, hunting deer, and using native seed plants in the sand dunes of the Gobi desert. The meat, milk, grains, and fruits of the five animals having horns (camels, horses, cattle, sheep, and goats) adapted to the ecosystem of the Gobi steppe supplied sufficient amounts of nutrients necessary for the body of the people of this area (Batsukh et al. 2013). Most of the livestock kept by the Huns were sheeps but horses, cattles and camels were few. Gradually the tribe developed the processing animal products such as hair, wool, milk, meat, and leather, the classic form of nomadic life.

The nomads were provided the essential proteins and minerals, necessary for the human body, from animal and animal raw materials, and enriched them with plant-derived substances such as carbohydrates, phenolic compounds, fiber, vitamins, and unsaturated fatty acids. Since then, fermented foods such as fermented milk, yogurt and chutney have been used in the daily diet. These fermented foods are known as probiotic foods in today's science. There are historical records of vegetables being grown and used for food during the Kidan Dynasty. According to Chinese sources, the northern neighbors opened many large markets to trade animal meat, milk, skins, game skins, wool, and hair as well as plant species and therefore, had in influence on Mongolian diet. Mongolian tribes started using foreign foods such as tea, sugar, and white rice from this period.

3.2.5 Period of the Mongol Empire

During the period of Mongol empire, the pastoralist tribes established relations with foreign powers and developed technological advancements in the field of war strategy and animal husbandry (Batsukh et al. 2013). At the same time, foreign foods were imported through trade and tribute. The more powerful and wealthy a nation is, the more diverse and high-quality its population's diet is. During the 1st century BC, the Khunnu dynasty created the classic technology of meat, milk and grain processing by herding animals in the steppe region, while this model was further developed during the ancient Turkic and Uighur periods and reached its peak during the Mongol tribes.

Dairy products are the main food of Mongolians, and it is noted that they drink milk from sheep, cows and camels, and eat meat from wild animals and birds. Regarding plants, it is noted that millet is eaten in winter, and bread, vegetables, wine, beer, and honey were received as gifts from foreign countries.

Even today, when Mongolians go on long-distance campaigns, they carry two leather jugs for milk and a clay pot for cooking meat. The dairy products generally used by modern Mongolians, include Shim alcohol, fermented milk, milk powder, curd, and curd with egg. Mongolia vodka, or airag, is drunk in large quantities in the summer, and it is fermented in large vats until the oil comes out with a wooden plunger with a perforated ring. Cow's milk was kept as a drill, and the harvested drill was put in a well-boiled sheep's stomach and kept frozen. The meat of sheep and horse was used as food and in case of illness, but beef was dried and used as a meal more than that of other animals. Grains and vegetables, which contain substances necessary for the human body, were an important source of food for the population during the Mongol Empire. Amuu rice was the food used by the population of the Mongol Empire. During the 12th and 13th centuries, the Selenge River basin was inhabited by tribes of people who specialized in farming, cultivating black rice, barley, wheat, and millet. In addition, raisins, figs, plums, peaches, apples, pears, walnuts, fruits, and nuts, black pepper, cucumber, rice, oats, rye, snow melon, parsley, and some foreign tea plants were also used as foods.

Dairy products, including fermented milk, are important in Mongolian soldiers' food consumption. The technology of fermented drink made from mare's milk is regarded as an intellectual property of Mongolia. Meat also played an important role in the diet of Mongolian soldiers. For Mongolians, the way to cope with the cold weather and climate was to eat foods that contained a lot of calories. Meat and fat of five horned animals occupy an important place among these high-calorie foods. While using animal meat, a unique technological solution was devised to process guts, head, and blood without waste, which has been passed down to the present day. Dairy products and animal meat played a decisive role in the formation of Mongolian warriors who were physically fit and mentally tough, who found the ability to resist disease and adapt to the harsh and harsh conditions of nature. Thus, one of the secrets of Genghis Khan's conquests can be seen in connection with their eating habits and types of food. Researching the composition of food used by Mongolian warriors demonstrated that it is rich in perfect animal proteins, living microorganisms, vitamins and minerals (Batsukh et al. 2013). These substances have an important physiological role, such as determining the immunity and physical development of the human body, and conditioning bone strength to intensify metabolism.

3.2.6 Period of Manchurian Rule

The great trade route that connected the East and West continued to play an important role in the food consumption of the nomads after the collapse of the Mongol Empire. It was important to exchange animal raw materials with agricultural and hunting furs and goods with neighboring countries. In the following years after the collapse of the Great Empire of the steppes, the ancient practice of enriching livestock with grains, game meat, and wild fruits continued in Mongolia. Horses, sheep, and cattle were relatively abundant among the livestocks. During the Manchurian rule, deer hunting was common in the lives of Mongolians, and a large percentage of people, especially poor people, were provided their food source with game prey. Fur animals were hunted and traded. The Mongolian plain became one of the free trade zones between China and Russia. In 1727, Russia and Mongolia-Qin state treaty was signed and the trading city of Svoboda-Maimaa was established (Bazarova 2011). This agreement stipulates the conditions for a 200-person convoy of Russian merchants carrying game fur, hides, medicinal herbs, and game animals to pass through Mongolia and arrive in Beijing. In Maymaa market, West England velvet fabrics, fruits, berries, pepper, perfumes, fish, flour, tobacco, paper, silk, crepes, sweets, pottery and porcelain are sold (Bazarova 2011). According to researchers, the tea plant was originally used only for medicinal purposes. The Mongolians of this period were already used to rice, tea, sweets, and ginger, so they exchanged them for raw materials of animal origin.

Many of today's concept of proper nutrition, such as the emphasis on vegetarianism, the practice of fasting, limited eating, the healing of disease through food, and strict observance of traditional foods, were ancient religious practices. Modern science has proven that appropriate consumption of vegetarian food at the specified time reduces the content of harmful metabolic substances resulting from high consumption of animal protein and facilitates the functioning of the digestive organs (Batsukh et al. 2013).

3.2.7 Period of Modern Food Production

At the beginning of the twentieth century, the world began to produce food intensively to feed the increasing population and it was possible with the progress of scientific development and technological inventions. With the development of food production technology, hundreds of types of food have been added to people's diet, the quality of the foods has been improved, the safety has been ensured. Similarly, the food habit of Mongolia was also influenced by globalization. At this time, the nomadic lifestyle continued in the Mongolian plains, and a certain section of the population began to move to the settled areas. Dumplings, pancakes, tofu, *yewen*, *tanzur*, *mayur*, pickled spices, Chinese tea, and using Chinese porcelain cups and utensils from the south become popular among the population. Mongolians started using a lot of processed foods such as bread, cookies, sweets, Georgian tea, canned food, and vegetables like cabbage, carrots, and learned to use spoons and forks in the European way.

Intensive livestock industry began in 1960. Irrigation of pastures, measures to fight against infectious diseases and hay harvesting were started. Measures such as improvement of animal breeds, pure breeding of local hybrids, cross-breeding of productive animals, and establishment of academic institutions and schools began to train specialists. Since 1990, the number of livestock reached more than 90 million.

Using the milk and meat of the livestocks, the method of making traditional food products such as fermented milk, *urum*, cream, *eezgii*, mongolian vodka, and borts was not much different from the time of our ancestors. New types of products such as butter, cheese, drinking milk, yogurt, ice cream, sausage, smoked meat, and toppings have been produced using modern methods.

In 1924, the rules of agriculture were approved, experts were invited from Russia, and the work of using agricultural tools was started. In order to increase the consumption of plant-based foods, vegetable cultivation was started throughout the country in 1941. As before, Mongolians mainly consumed animal meat and milk, and still extracted plant-based foods commercially and from nature. By cultivating and multiplying plant species, the amount of yield obtained from a unit area has increased, and thus the possibility of producing more products and providing food to more people has increased. The development of science and technology created the conditions for the creation of added value in the food industry. Crops and vegetables grown in the soil of Mongolia have dramatically changed the food consumption of the population. Plant-based foods, including rice, flour, and vegetables, have become the staple food of Mongolians. Significant proportion of the vegetables, fruits, sweets, flour and rice sold in the Mongolian market are supplied by neighboring countries (Tumurjav 1989, 2003). Since the 1940, along with the increase in the production of agricultural and agricultural products, chicken, pig, and fish breeding have been created, and the products of this industry have played an important role in the livelihood of Mongolians. By the beginning of the twenty-first century, Mongolia has more than 173 types of edible plants, about 20 types of fruits, and 375 types of mushrooms (Tumurjav 1989, 2003).

3.3 Traditional Foods and Drinks and Their Safety

Mongolians developed a volume of traditional wisdom to prepare traditional foods and drinks that are rich in nutrients and can be stored well. The technology based on the indigenous knowledge system (IKS) of Mongolians is characterized by the fact that the main food items are produced in a clean form with little effort required in nomadic and settled conditions. However, from the beginning of the twenty-first century, sedentary life, urbanization, and free trade and globalization, arguably westernization began to have a significant impact on dietary transition. The consumption of fast food, processed and ultra-processed food, often characterized with high carbohydrate, oil and salt, has been increased. As a result, the consumption of natural or traditional foods has been decreased. This dietary transition could result into increasing number of lifestyle diseases such as cardiovascular disorder, diabetes, even cancer (Dugee 2009; Dugee et al. 2009). Proteins, carbohydrates, fats, vitamins, minerals, and water should be obtained from foods. Because there is no perfect food that contains all the nutrients, it is recommended to consume a variety of foods in certain amounts and proportions and therefore, food diversity is essential. Excess or deficiency of these nutrients can cause diseases in the human body. For example: lack of protein leads to loss of tissue regeneration, weakening of the immune system, physical and intellectual development, and anemia due to iron deficiency. Young children, adolescents, and pregnant women are more susceptible to malnutrition.

3.3.1 Mongolian Traditional Dairy Products

As already stated above, for Mongolia which is mainly engaged in animal husbandry, one of the main foods is milk and dairy products (Indra et al. 1976; Gombo 1992; Indra 2000). Fat, protein, and sugar contents of the milk are processed into different types of products *viz.* fat type products, protein type products and fermented products (Fig. 3.1).

3.3.1.1 Fat Type Product

Most of the fatty acids in milk fat melt at a lower temperature than the human body temperature, so they melt quickly and are fully absorbed (Indra et al. 1976; Indra and Batsukh 2000). Milk fat is broken down into glycerol fatty acids, which play an important role in metabolism. Milk fat contains different essential polyunsaturated fatty acids such as linoleic, linolenic, and arachidonic acids. Phospholipids, which belong to lipids, are in the film of milk fat bubbles and participate in the body's protein synthesis and activate the brain. Cholesterol is responsible for regulating sex and adrenal hormones, neutralizing toxins, and hematopoiesis. The composition of

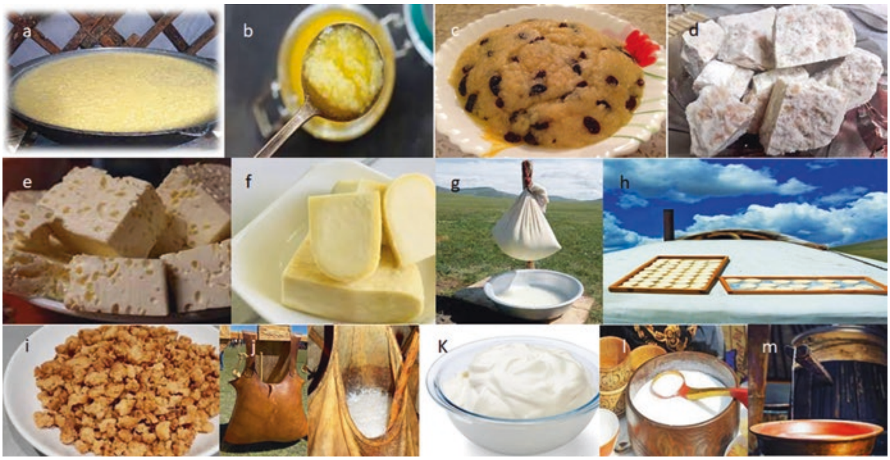

Fig. 3.1 Milk and traditional dairy products of Mongolian culture; (**a**) Fat of pasteurized milk; (**b**) Ghee; (**c**) Melted butter; (**d**) Enriched fat of milk; (**e**) Foremilk; (**f**) Mongolian cheese; (**g**) Process of separating of whey from curd; (**h**) Curd drying process; (**i**) Dried milk protein with whey; (**j**) Fermented milk of horse kumiss; (**k**) Mongolian yogurt; (**l**) Fermented milk of Camel; (**m**) Process of distill milk vodka

the oil includes oil-soluble lecithin, lipids such as sterols, vitamins A, E, D, but to a lesser extent water soluble vitamins (C, B12), and nicotinic acid (Indra et al. 1976; Indra 2000; Indra and Batsukh 2000). Fat has twice as many calories as protein and carbohydrates have.

Urum Urum is a creamy pudding that sits on top of skimmed milk.

Ghee The unique paste separated from the oil is called ghee (Fig. 3.1b). Depending on the local customs and climate, the method of making ghee varies. In the Western, Southwestern, and Southern provinces, oil is produced by churning animal milk and yeast, while in the Central and Eastern provinces, it is customary to produce oil by melting. Chromatographic analysis of the composition of fatty acids in yak ghee showed that the ghee contained the most oleic acid (41.8%), linoleic, linoleic, and stearic acids, which are essential for human, 15.54%, saturated acids (48.96%), and unsaturated acids (51.04%) (Indra and Batsukh 2000). Regular use of ghee protects against hardening of the arteries, osteoporosis, and loss of sexual and renal hormones, fatty liver and accumulation of excess fat on the vessel walls (Khishigmaa 2013). However, if the amount is exceeded, there will be symptoms such as vomiting and diarrhea. In some cases, tea with ghee, eating barley flour kneaded with ghee, and gargling with ghee are used to suppress gas.

Khailmag A kind of unique pudding made by melting new and fresh oil, extracting ghee and adding a small amount of flour or starch to the remaining fat is called khailmag. Enriched with sweet puddings such as candy, buram, and raisins, it can be used fresh or frozen for food.

3.3.1.2 Protein Type Products

Dried protein products are adapted to the dry climate of Central Asia, such as dried curds and *eezgii*, are widely used by Mongolians. These products are suitable for long-term storage.

Foremilk Mongolians call the thick yellow milk of newly calved animals protein. After calving, the protein milked in the first 1–2 days is called colostrum protein. Mongolians process the protein of animals other than horses. Put the egg whites in a pot and slowly heat it until it boils and thickens (Fig. 3.1e).

Mongolian cheese Mongolian cheese is made from cow, yak, sheep and goat milk (Fig. 3.1f). Cheese technology is available in almost all regions of our country. It consists of the stages of heating milk, curdling, molding and squeezing. Only in some areas of the western province, there is a custom of using stomach enzymes for preparation. Compared to other types of cheese, Mongolian cheese does not require cutting, salting, or processing. The taste and quality of Mongolian cheese is unique. Mongolian cheese is also called raw *edem*. Raw milk cheese is considered better in quality. *Byaslag* is one of the most popular dishes of Mongolians, and it is mainly used fresh.

Curd After distilling the cow's milk to obtain alcohol, the thick curd is poured into a container other than the distillation pot and left for 10–12 hours to cool and allow the protein to settle. Then put it in a cloth bag and press it down with something heavy. When the moisture content is 65–70%, add about 30% of the weight of the curd and filter again. Thus, by diluting it with milk and rinsing it, the acidity of the curd is reduced and its taste is improved.

Yoghurt curd fresh coated yogurt is boiled for 30 minutes on low heat and strained. Filtered and ready curd is stored in stomach and stomach. Curd is made in the evening in the fall and kept frozen throughout the winter, and is intended for use in winter and spring. But in summer, curd is used to make curds and fingers. A good quality curd is a protein product with a uniform density and sour taste (Batsukh 1995a, b).

Dried curd Dried curd is rich in protein and fat and is suitable for storage and transportation. Dried curd is made from whole animal milk, especially sheep's milk, in a delicacy in Mongolian culture. 1–1.5% skimmed milk curd is considered to be the most suitable in terms of quality (Batsukh and Indra 2002). Dried curd is rich in nutrients especially vitamins C, D, B, and long-term storage does not cause significant changes in taste and composition. It is an important daily food product for the rural people. Also, people believe that a certain amount of hard *aaruul* has the quality of strengthening gums and teeth. Dried curd contains about 90% dry matter, 30% fat, and 10% soluble protein.

Eezgii *Eezgii* is made with the milk of animals other than mare's milk. It is prepared in spring and autumn, after calving and before drying. In the early spring and late autumn, it is difficult to maintain a constant temperature in the home to make other types of lactic acid porridge (the conditions for the growth of lactic acid bacteria).

3.3.1.3 Fermented Milk Product

Fermented milk products are divided into two categories: lactic acid products and lactic acid and alcohol products. Yoghurt, mare's fermented milk, cow's milk and cow's milk, many types of curds, cheese are not only the daily food of the herdsmen, but also intermediate products or raw materials for the processing of many types of dairy products (Damdinsuren 1978, 2001, 2002). Mongolians use *Iseg Idee*, which is a probiotics, since ancient times.

Mongolian yogurt Mongolian yogurt is a popular dairy product widely distributed in the country. Curd is made from sheep, goat, cow, and yak milk. Taking into account the quality of milk used to coat yogurt, it can be divided into raw milk, skimmed milk, and processed milk. The fat content of raw milk yogurt is at least 3.2%, skimmed milk is 1.3–1.5% fat, and processed milk is 0.05–0.07% fat.

Ukher bogi dotke The fermented product by combining the oxidation of lactic acid and alcohol in wooden barrels and containers is called *dokte*. Another vernacular name of the drink is *Khoormog*. In the western provinces mare's fermented milk is known as *chigae*.

Khoormog Since milk has a lot of carbohydrate, the combination of lactic acid and alcohol will create suitable conditions for oxidation. *Khoormog* is thicker than mare's beer, but it melts in the mouth with a foaming sound, a sour taste, and a unique carbonated drink that tingles the lips and nose. The fat content of the sausage is 3.3%, protein is 3.76%, and total dry matter is 12.6% (Batsukh 1995a, b). Khoormog is unique in its nutritional and therapeutic qualities, and because it is mainly composed of globular proteins called albumin and globulin, it creates a uniform, very unique structure that does not cause dense edema and does not secrete whey. This milk not only reactivates the digestive system, improves the physical strength of the body, but also medically treats chronic diseases of the liver, gall bladder, and kidneys (Batsukh 1995a, b).

Mongolian milk vodka Fermented with milk of various animals is distilled to produce Vodka. Mongolians call this process "pot distillation". The essence of the pot distillation process is to separate the alcohol from the oxidation of sugar in the milk into a liquid by evaporating and cooling it back. Mongolian pot brewing equipment consists of a pot for boiling fermentation, a cover to create a closed environment, a jar for cooling water, and an atrium for drinking alcohol. The distillery pot is made of cast iron, the fins are made of aluminum, and the bucket and atrium are made of wood.

Traditional milk processing technology is relatively simple, labor-intensive, does not require sophisticated equipment, uses a small number of simple containers and equipment, and is characterized as a zero-waste technology.

3.3.2 Mongolian Traditional Meat Food

Meat occupies a major part of Mogolian diet (Fig. 3.2). There are more than 200 types of national dishes in which meat is the main ingredient and among them there are more than 70 types of food made from the intestines of animals. Meat has been processed by methods such as cooking, roasting, smoking, and burying. To name a few delicacies, especially foods that Mongolians bring to their most honored guests are *bood*, *khorgo*, fried mutton juice, etc. Mongolian soup is a dish made by enriching meat with plant-based foods.

Fig. 3.2 Traditional meat products of Mongolian culture; (**a**) Whole sheep; (**b**) Back of the sheep; (**c**) Mixed meat in pericardium; (**d**) Goat meat with stone; (**e**) Boiled meat with stone; (**f**) Gobi boiled meat; (**g**) Mongolian barbecue; (**h**) Whole meat; (**i**) Head and leg; (**j**) Nutrient dense soup; (**k**) Fish; (**l**) *Tegmen*; (**m**) Dried meat; (**n**) Dried horse meat; (**o**) Salted meat; (**p**) Frozen blood with internal organs

Mongolia's animal husbandry is dominated by pastoralism, rooted in centuries-old traditional nomadic animal husbandry. Primarily the livestocks include camels, horses, cattle, sheep, and goats. The recommended meat (boneless) consumption for Mongolian people is 6 kg per month in the 9 months of the cold season, and 4.5 kg in the summer months, i.e. a total of 67.5 kg of boneless meat per year. The meat consumption of urban and rural population differs (Damdinsuren et al. 2002). Mongolians not only use fresh meat, but also store it for a long time by drying, smoking, salting, and freezing. The above-mentioned methods have been used in food, either alone or in combination, to extend the shelf life of meat and improve its taste.

3.3.2.1 Thermally Processed Meat Products

Whole sheep The most honored meal of the Mongolian national dish is a big whole sheep (Fig. 3.2a). It is made from the belly of the sheep, and the remaining meat is cooked without breaking it.

Back of the sheep This is a preparation of sheep's spine including the two ribs, and fat tail (Fig. 3.2b). Since the rump is a very respectable delicacy in Mongolian traditional cuisine.

Pericardium It is a dish made by putting meat in the skin of an animal's heart, seasoning it with salt and onion, and then wrapping it with string or stringing it with wood (Fig. 3.2c).

Boodog Meat is cooked in its own moisture without the use of water and seasoned with salt, onion, and cumin and a little water to make the soup. This item is prepared with stones. Ingestion of the soup and rub the palms on a hot stone are believed as an ailment of fatigue and gastritis.

Khorhog A dish similar to *boodog*, but cooked in a container with a tight lid.

Jimbii A kind of celebratory meal similar to making *khorkhog*, which is said to have originated from the Gobi Provinces, especially the Umnugovi Province. Jimbii is unique in that the meat is fried and cooked in its own oil without the use of stones, but with various vegetable spices.

Bulmag Prepared and seasoned whole meat is peeled, wrapped in birch cork and buried in a hot pile of dung and wood firewood.

Shorlog When grilling game meat, Mongol warriors used to put their shields on an open fire and stir, skewer, and fry it with a sword or bow arrow, which later became famous as "barbecue".

Whole meat meal Only meat with bones cooked in salted water.

Heads and skins There are ways to peel the heads of small animals and wash them with hot water and cook them, or to clean them and cook them without skinning them.

Three nutrients soup It refers to the soup made by removing the meat from the shank bone, rump bone, and head bone of sheep and cooking it in a closed container.

Fish meat meal Mongolians have been using fish for food since the Sianbi period. The records of the Mongolian secret bureau and other sources such as writings of scholars like Rashid Ad din, Plano Carpini, V. Rubruk, and Chang Chun Bumba provide information about the widespread use of fish by the Mongols. Fish meat is prepared in many different ways, such as cooking, grilling, baking, slicing, battering, making dumplings, pancakes, etc. In addition to salting, curing, and freezing, the caviar was mixed with a little ghee and flour and eaten as pancakes.

3.3.3 Mongolian Ancient Meat Feast

Tegmen It is Khamnigan Buriad Zona dish, which consists of horse's veiled liver, core, meat, and horse meat, which is cooked in water after adjusting the taste with salt and *mangir*.

Uralduur It refers the meat from both sides of the sheep's rib, season it with salt, onion, and garlic, turn the esophagus inside, and give it to the boys as "go fast and strong" and to the girls, "go smart and beautiful".

Sagsai It is a preparation of beef with fat in water, with the salt.

Tuley This is the name of the boiled sheep's head and the delicacy is famous in Buriyad.

Tugnu It is a Hamnigan dish in which the meat is undercooked inside the bod and seasoned with salt, *mangir*, and anise, then rolled in flour and baked.

3.3.3.1 Meat Food with Extended Shelf Life

Borts dried meat. The method of browning meat, which has been used by Mongolians for a long time, is a unique technology based on the nature and climate of our country. The essence of the meat curing process is that after cutting the meat, it is cut into small pieces, frozen in the natural cold, then exposed to the wind, and the moisture is evaporated without thawing back. Meat food prepared in this way is called *borts*. *Borts* is made in winter, usually at the end of November and December. By browning the meat, the biochemical processes that take place in its structure and the oxidizing action of bacteria are basically stopped. *Borts* is a food suitable for nomadic life, as well as a suitable food for long journeys and tourism. Mongolians make borts with beef, camel and goat meat, and horse and mutton meat is usually fresh or frozen.

Kaz salted horse meat. It refers to the dried intestine of horse seasoned with salt. It is one of the most respected dishes of the Kazakh people of Bayan-Olgii province.

Shuuz It refers to the fresh meat seasoned with salt and preserved in a sealed container. This is one of the traditional ways to preserve and use fresh meat during the heat of summer and autumn is the method of making *shuuz*.

Khyaramtsag frozen blood. Mongolians use the fattened meat of small and large animals for winter food by extending the storage period through the winter and spring using the above methods. Put the blood of the animal into the stomach and small intestine and freeze the lungs and liver in the middle. Blood can be poured into the small intestine of the stomach and kept separately. In winter, it is usually used in soups, but it can be used in all other dishes. It is a nutritious food that is very useful for blood circulation and relieving fatigue.

3.3.4 Plant-Based Foods

Although Mongolia has an extreme climate and four seasons, many kinds of fruits and vegetables, such as legumes and sweets, have been wisely used since ancient times (Avdai et al. 2003). Mongolians mainly cultivated barley and wheat with a little black rice or small grain and sago or triangular rice. There were two species that were most suitable for Mongolia's soil and climate: barley and wheat (Batsukh et al. 2013). Figure 3.3 represents some of the plant based traditional food items.

Wheat flour Flour is a powdery crumb obtained by cleaning the grain, processing it with water and heat and sifting it in a mill. The origin of flour industry dates back to the Stone Age or Neolithic period. As the demand for flour grew, water, wind and electric mills were developed using horses, donkeys and natural power. Mongolians have traditionally made many types of baked goods using wheat flour. The most common of these are loaves and normal buns. The basis of the technology for making normal bread or jam products from pods is based on changes in the structure and properties of its starch and protein compounds. When water is added to wheat flour to prepare dough, colloidal and biochemical processes take place. One of the first

Fig. 3.3 Traditional plant based foods of Mongolian culture; (**a**) Pudding made with plain pastry; (**b**) Comb style pastry; (**c**) Rope style pastry; (**d**) Barley flour with ghee; (**e**) *Polygonum viviparum*

products that Mongolians began to make and use was fennel, and the tradition of using it continues to this day. Flour, water, oil, flour, and sugar are used as raw materials for the bean paste.

Shape pastry It is assumed that it was first made for religious occasions in the sixteenth to seventeenth century, when Zoroastrianism began to spread widely in Mongolia. Normal buns are round, oblong, oval, and still printed with beautiful symbolic patterns. A simple pastry is more of a ritual than a food. The main ingredients are good quality wheat flour, milk, butter, ghee, butter, sugar, and some sweeteners.

Samnaa pastry It is a bun prepared by adjusting the thickness of the wheat flour dough and flattening it according to the needs, then cutting it into oblong squares and cutting three rows in the middle.

Gurmel pastry It is used in the western provinces of our country for daily and ritual food preparation. It is similar to other types of bread in terms of recipe and ingredients, but different in shape. The length of the rolled pastry prepared in this way is approximately 17–20 cm, and the width is 5–7 cm.

Barley flour Barley flour is prepared by roasting the barley from the mixture, separating the husks and removing the seeds, then steaming gently, removing the husks completely, soaking and sifting the husks, and milling them. Such flour is called *zambaa* in Western Mongolia. In the traditional folk method of making barley flour, the barley is whitened, harvested, sieved, and threshed. Barley flour contains 6–8% moisture, 1.8–2.5% ash, 13.5–20.5% protein, 59–63% starch, 1.9–3.5% oil. Barley flour and brown rice have high nutritional value, are easily digested by the human body, and contain a lot of fiber, minerals, and unsaturated fatty acids such as oleic and linolenic (Chimedtsogzol and Dugersuren 1974).

Because of their high nutritional value and good shelf life, sorghum, and sorghum bread are commonly used by nomadic herders. The composition of animal fats is dominated by saturated fatty acids, and on the other hand, the composition of vegetable oils is dominated by unsaturated fatty acids (Batsukh 2012; Batsukh et al. 2013). The quality of animal and vegetable oils depends largely on their polyunsaturated acid content. They are of physiological importance as they form the structural elements of the body's cells. Linoleic and linolenic acids are essential fatty acids as they cannot be synthesized by the human body. Arachidonic acid is synthesized in the body with the participation of linoleic acid, vitamin B6 and biotin (Batsukh 2012, Batsukh et al. 2013). Palmitic, stearic, myristic and other acids are the main sources of heat, and they melt at high temperatures and are solid. Excessive use of oils containing these acids has some negative effects on the body. Herbs should be consumed as it contains micronutrients, fibers, etc.

Berries and other fruits Natural wild berries are very commonly used for medicinal purposes. Fruits are useful for improving the digestive process, increasing the secretory activity of the digestive process, and regulating the activity of beneficial intestinal microorganisms.

Fruits are a rich chemical composition containing dry matter, sugar, various vitamins, amino acids, starch, minerals, salt, carbohydrates, proteins, oils and biologically active substances. In the mountains of Khangai, Khentii, Khuvsgul, and Altai, and along the river basins, many plants with sweet seeds and fruits such as gooseberry, rockberry, strawberry, *Prunus padus*, *Rosa dahurica Pall* sea buckthorn, etc. grow. Berries and fruits were mainly used by Mongolians for medical purposes. The plants grown in Mongolia surpass all other types of food in terms of the content of biologically active substances that have a positive effect on the human body, and they are considered natural medicinal preparations.

One of the plants that Mongolians have traditionally prepared and used for food is *Polygynum cordifolium Turcz.* Many types of plants have been used by humans for the treatment of animal diseases, food, and agriculture, and currently more than 2000 species of medicinal plants belonging to about 100 genera have been studied (Georgievski et al. 1990). Among these, important plants with medicinal properties such as gorse, sea buckthorn, antelope, *Prunus padus*, *Crataegus sanguinea Pall*, *Glycyrrhiza uralensis Fisch*, *Plantago major L*, *Bergenia crassifolia L Fritsch*, blackcurrant, *Cynomorium songaricum Rupr*, white mushroom, and saffron are widely used in food (Volodya et al. 2010).

Polygonum viviparum is very widespread in every province of *Polygonum viviparum /mekheer/* Khangai region and grows in mountain slopes. In the Mongolian folk hospital, its rhizomes are used in medical and veterinary clinics for diarrhoea, hemostasis. The extract is applied in cases of inflammation and purulent inflammation of the mucous membrane of the mouth. Because it is starchy, it is mixed with white oil and used as food. Traditionally *Mekheer* oil and *Mekheer* curd are prepard by drying and grinding *Mekheer* root and mixing it with oil and curd. The picture below shows the widely growing *Mekheer* in our country (Georgievski et al. 1990).

3.4 Conventional Packaging

Traditional and modern food products' containers and packaging with good quality and craftsmanship is required as they have positive effects on the health of the population and the environment. Ecologically clean packaging has an important effect on the process of delivering finished products to consumers. The Mongolians used tools and packaging adapted to the unique conditions of migration, which have been passed down to the present day. Figure 3.4 represents the traditional utensils, food packaging and storing techniques. Traditional utensils and packaging can be divided into two general categories: hard and soft tissue. Iron, wood, and pottery utensils are considered to be of hard tissue origin, and those made of animal skin, wool, and cloth are considered to be of soft tissue origin. Archaeologists have noted that pottery and porcelain vessels were made by tribes who grew crops and vegetables because of their connection with the land and water (Khukhuu et al. 2009).

Fig. 3.4 Traditional utensils and packaging of food in Mongolian culture; (**a**) 270- year old pot weighing 541 kg from Manzushir Monastery in Tuw province; (**b**) Silver cup and bag; (**c**) a cup made up of tree bark; (**d**) copper cup and *Dombo*; (**e**) Wooden pot; (**f**) Milk bucket; (**g**) *Dombo*; (**h**) Ghee into small intestine; (**i**) Mongolian yogurt in *Khukhuur*; (**j**) Campaign packs and bags; (**k**) Packaging boiled blood

3.5 Conclusion

Mongolians with a nomadic culture have developed their foods and drinks that are prepared in a simple way and packaged wisely, suitable for traveling and long-term storage. The country represents an example model of intergration of scientific advancement and rich traditional or culture. In most of the cases the diet of the present day represents their dietary tradition but the production and processing systems have been improved with the advancement of technology.

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Chapter 4
Current Status of Edible Insects in the Context of Dietary Transition in Western French Africa: A Case Study from Benin

Séverin Tchibozo

4.1 Introduction

The Republic of Benin, formerly known as Dahomey, is situated in West Africa between latitudes 6° and 13° N, and longitudes 0 and 4° E. The country is bordered by Togo to the west, Nigeria to the east, Burkina Faso to the northwest, and Niger to the northeast. In the surrounding countries as well as the Southern regions of Benin local inhabitants consume a variety of insect species as a planned part of their diet (Tchibozo et al. 2005; Grabowski et al. 2020; Ghosh et al. 2021).

At present days, the majority of the people of Benin like foreign foods such pasta, milk and dairy products, wine etc. Only a small population from the village depends on the Non-Timber Forest Products (NTFPs) as their livelihood including foods. The edible insects not yet accepted to a large proportion of population for the diet. I am not sure the insects will the future dietary transition in Republic of Benin. The global economic development and westernization influences the several young people.

One of the goals of the Millennium Objectives for Development (MDG) is to eradicate hunger and malnutrition worldwide. Edible insects present a viable solution as they are a traditional food source in some African countries and are part of the Non-Timber Forest Products (NTFPs). Living in proximity with nature local traditional people developed a volume of dynamic indigenous knowledge of utilizing the available ecological resources for food as well as medicines. However, with the rapid urbanization, and changing of landscape, migration, etc. are crucial drivers for the transformation of the traditional food systems and loss of indigenous knowledge system associated to it (de Bruin et al. 2021).

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4.2 Overview of Entomophagy in Africa with Special Emphasis on Benin

Worldwide about 2140 insect species have been reported as edible (Mitsuhashi 2016). As of the best of my knowledge, 31 local communities have been surveyed in 10 countries in west Africa (Fig. 4.1). In Benin, Tchibozo (2005) conducted the first study that investigated entomophagy behavior of the country. The study reported 5 edible insect species; however, as of now 22 insect species have been reported as edible or for the use of therapeutic purposes. The consumption of insect was not accidental or due to food scarcity but the insect ingestion can be well described as the cultural attribute and considered a delicacy among the local people (van Huis 2003). Table 4.1 represents a list of common edible insects in Africa. However, consumption pattern differs with different ethnic communities, belief systems, rural and urban environment etc. (Manditsera et al. 2018; Ghosh et al. 2021). In Ghana the droppings of the grasshoppers Aka Akranti, are used by the indigenous people of the region of Brong Ahafo, to give a good taste on the local fish soup (locally known as *Abunuabunu*). Figure 4.2 represents consumption of edible insects by different ethnic groups in Benin (Anii, Fon, Nagot and Wama) and other countries in West Africa.

Fig. 4.1 Thirty-one local communities have been surveyed in 10 countries in Africa

Table 4.1 Some common edible insect species of Africa in Benin

Orders	Family	Scientific name	Local or vernacular name[a]
Termites	Termitidae	*Macrotermes falciger Gerstacker*	Etoutou
Orthoptera	Acrididae Cyrtacanthacridinae	*Acanthacris ruficornis citrina* (Audinet-Serville, 1838)	Tchoubou
	Acrididae Cyrtacanthacridinae	*Ornithacris turbida cavroisi* (Finot, 1907).	Tchoubou
	Acrididae Hemiacridinae	*Hieroglyphus africanus* Uvarov, 1922.	Tchoubou
	Grillydae	*Brachytrupes membranaceus* Drury	Afomon
		Brachytrupes sp.	Baka
	Oedipodinae	*Locusta migratoria migratorioides* (Reiche et Fairmaire, 1850)	Gountanta
	Acrididae Hemiacridinae	*Spathosternum pygmaeum* Karsch, 1893	Igbè
	Tettigoniidae	*Conocephalus sp.*	Igbè
	Gomphocerinae	Indéterminée (IND)	Igbè
	Pyrgomorphidae	*Zonocerus variegatus* (Linnaeus, 1758).	Alankpa
	Tettigoniidae Conocephalinae	*Pseudorhynchus sp.* 1.	Guègbelè
	Tettigoniidae Conocephalinae	*Pseudorhynchus sp.* 2.	Guègbelè
	Tettigoniidae	*Ruspolia sp.*	Guègbelè
	Acrididae	*Truxalis sp.*	Guègbelè
Coleoptera	Hydrophilidae	*Hydrophilus sp*.	Kountounnougoussiré
	Buprestidae	*Sternocera interrupta* (Olivier, 1790).	Kokouanré
		Steraspis castanea (Olivier, 1790).	Kokouanré
	Scarabaeidae, Cetoniinae	*Pachnoda cordata dahomeyana*	Pipinou
	Dynastidae	Indéterminée (IND)	Woïwo
	Curculionidae	*Rhynchophorus phoenicis* F.	Kpitran
	Dynastidae	*Oryctes spp.*	Atrandèpkometon

[a] at Benin

Cultivating edible insects in Africa is not common practice and in most of the cases edible insects are harvested from the wild environment. Insect species are known to cause seasonal damage to agricultural crops and perennial cultures, such as oil palm and other plants. The harvesting of insects responsible for destruction of crops, would equally benefit the agriculture in African countries by eliminating pests. For example in Niger, thousands of locusts are collected in the savannas annually. They are sold at local markets in Benin and represent an important revenue

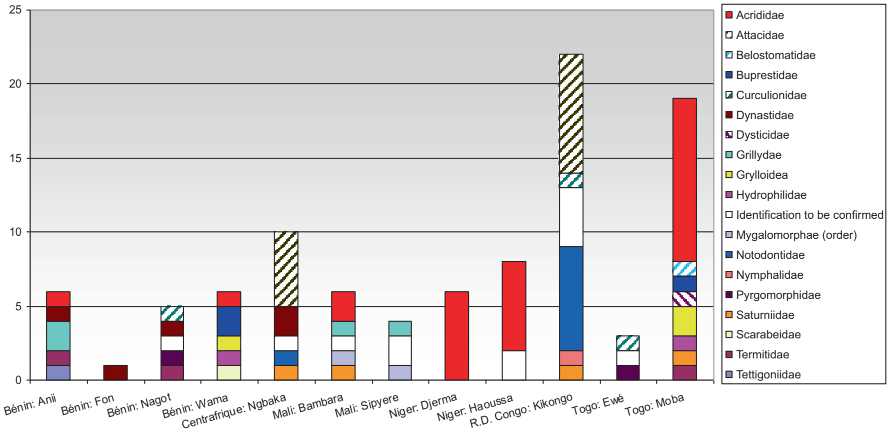

Fig. 4.2 Edible insect consumption by insect family in ethnic groups in Benin (Anii, Fon, Nagot and Wama) with comparison to other countries in west Africa. (http://gbif.africamuseum.be/lincaocnet/)

stream for local communities as well as the Nigerian diaspora in Benin. However harvest from the wild cannot ensure the continuous supply of the food item and at the same it does not ensure the safety and nutritional quality of the food insects. Moreover, harvesting from the wild does not advocate the nature conservation. Therefore, to avoid the loss of the traditional food a sustainable production facility is required to be developed.

4.3 Nutritional Potential of Edible Insects in the Context of Africa

Large volume of scientific evidences demonstrates the high nutritional quality of edible insects (Rumpold and Schlüter 2013; Meyer-Rochow et al. 2021). To cite an example, Mariod (2020) analysed the energy content of the desert-locust (*Schistocerca gregaria*) and found that 179 kcal/100 g with a protein content of 14–18 (g/100 g fresh weight). Hundred grams of cricket flour meal contained 31.8% of proteins and caterpillars meal contained 38.8% (Tchibozo et al. 2016). Mohamed (2015) analysed migratory-locusts (*Locusta migratoria*), where the preliminary results indicated the presence of (96.2%) dry matter in 100 g. Other nutritional values included: Crude protein (50.4%), crude fat (19.6%), carbohydrates (4.8%), crude-fiber (15.7%), and ash (6.2%).

Malnutrition is a severe problem in Africa and more acute than anywhere else in the world (UNICEF 2022). More than 2 billion Africans suffer from deficiency in minerals and vitamins, and nearly 30% of the child population developing countries are afflicted by malnutrition (Roudart 2016). In West and Central Africa, 11% of the

Fig. 4.3 Biscuits fortified with insect powder

child population under 5 years of age suffers from acute malnutrition (UNICEF 2013). Assuming the good bioavailability, as edible insects are rich in micronutrients, especially minerals (Rumpold and Schlüter 2013; Meyer-Rochow et al. 2021), the ingestion of them could ameliorate the micronutrient deficiencies. Several African ethic groups have a long-standing tradition of eating insects for their nutritional value. The traditions are deeply ingrained in the culture as they are part of the mythology (Seignobos 2016). Insects' high nutritional value, such as protein, iron and vitamin A promotes health and wellbeing. Between February 2022 and April 2022, the impact of drought in Africa caused the number of children facing acute hunger, malnutrition and thirst to rise from 7.25 million to at least 10 million (UNICEF 2022). Biscuits fortified with insect powder were a welcomed solution to combat the issue of malnutrition in Africa (Fig. 4.3).

4.4 Past and Present in Benin

In a recent study conducted in Southeast Benin with the local communities of the Kétou and Pobé populations, we reported the current perception of entomophagy in the rural and urban population (Ghosh et al. 2021). We administered a semi-structured questionnaire to understand how these communities relate and understand to entomophagy, which is part of the local food culture. The study results showed that the majority of population is familiar with the use of insects as food source and a majority of the people is interested in insect consumption. No gender differences were found. As the most influential factor we identified the food tradition as determinants for the eating or rejecting the consumptions of insects. We found that knowledge of how to identify and select insect species, as well as different forms of preparation were not homogenous across the sample. Differences were depending on ethnicity, cultural traditions, age group and educational background. Awareness and promotion of edible insects throughout society will preserve the practice of entomophagy. It would further lead to the provision of much needed nutritional supplements to the poorer and disadvantaged sections of the society (Ghosh et al. 2021).

The rapid increasing of population, unanticipated climate change, higher environmental footprint of conventional livestocks and meat production systems have led to the search for alternative sustainable protein sources to meet the protein requirements in humans without negative impact on environment. In this regard, edible Insects are seen a major alternative protein source. A study in three ecological zones in North Benin investigated the diversity of edible insect species and the proximate properties of selected common insects used in traditional local diets. In total 20 edible insects belonging to 4 orders *Orthoptera, Coleoptera, Isoptera* and *Hymenoptera* were identified to be consumed throughout the year. It was also observed that each species was harvested with different methods. The quality attributes of consumption were distinguished according to the traditional technology-processing of insects collected: as boiling, sun drying, frying and smoking. These insects were found to be rich in protein (25.2–64.4 g/100 g dry matter), fat (16.4–46.8 g/100 g dry matter) and minerals (1.0–4.8 g/100 g dry matter). Not only general preservation of edible insect culture can act as economic incentive and to provide nutritional source, but also the safeguarding of the processing methods should be included in these local communities. This would greatly assist in reducing rural poverty and malnutrition (Hongbété and Kindossi 2017).

The production of edible insects had drawn much attention in developing countries to cope with the increasing demand for sustainable proteins in human and animal food consumption and reduce pressure on natural resources. In order to highlight the importance of edible insects, a study on the growth and food value of *Oryctes monoceros* larvae were conducted at the Faculty of Agricultural Sciences of the University of Abomey Calavi in Benin. The larvae were collected from rotten stems of palm oil (*Elaeis guineensis*) and the nutritional value was investigated. Analysis exhibited comparable, if not superior, nutritional quality of *Oryctes monoceros* larvae with other edible insect species and meat products (Gbangboche et al. 2016).

Food security is a critical issue for many low GDP countries across the African continent. In areas not suitable for for intensive agricultural production, local natural resources can play an important role, particularly those which are sustainable and on which people have relied on for centuries. In many regions of the world insects have been consumed for generations, and represent a reliable source of animal proteins among populations that otherwise have limited access to meat. The research conducted in Benin was motivated by the attempt to understand how edible insects could contribute to an area where food-security is a significant issue. Initially, our work focused on a case study of an insect-eating-community in Northern Benin, in the Atakora region. Not every community has the entomophagous tradition. Data on edible insects in the Wama-communities of the district of Tanguieta were collected administering interviews to focus groups and observing insect collections in two Wama settlements, Kosso and Cotiakou. Eighteen edible insect species were recorded, predominantly Coleoptera (52%) and Orthoptera (29%). Our project has found nine arthropod species eaten in the region, including new groups of arthropods, such as Hemiptera (family: Coreidae) and Acari (family: Ixodidae). Interestingly, collecting insect and their consumption was found to be an ancestral tradition in the Wama-community, mostly carried out by children. In light of malnutrition in North Benin being a major problem in young-age groups, promoting this tradition as well as exploring the potential of implementing small scale captive rearing of selected species could be a promising opportunity to further develop food-security in the region and beyond (Riggi et al. 2014).

Insects always have been, and still are, consumed in South Benin. They are a very important source of animal protein, able to successfully substitute some meats and improve the health of malnourished children. Various aspects have been investigated that include the species eaten, techniques of gathering, culinary usages, community consumption, and their economic importance (Tchibozo et al. 2005).

Insects are mostly consumed in the rural areas, mostly by the children for the taste from April to November, when the insects are widely proliferated. After the rainfalls the children put insects with joy into their basin under the lamps to collect winged termites. They also enjoy hunting crickets and grasshoppers. They grill them and eat them with the other insects that had been collected (Fig. 4.4). Specific insects, like the termite queen, are eaten raw because of their energy content. But mostly they are grilled or fritted. However, the consumption varies by region. Some people consume them discreetly because they don't want to be seen eating creepy-crawlies, yet others eat them openly. We have prepared biscuits to make insect eating attractive for everyone (Tchibozo et al. 2016; Fig. 4.3). The biscuits have a level of 8.88% to 10.6% of total raw protein content, 390 to 446 kcal/100 g energy. Their consumption would be an expected solution, at least to a certain extent, to reduce child malnutrition in Benin (Tchibozo et al. 2016).

There is an urgent need to breed insects to help the community to consume insect species and to reduce the collection of insects in the wild. Insects suffer from extinction due deforestation and urbanization of the areas, where insects have no longer access to host plants.

4.4.1 Benin Has Several Awards About Edible Insects

- 2015: Hoyrou SIGEF (Social Innovation and Global Ethics Forum) 2015, biscuits to reduce child malnutrition in Africa, https://www.sigef2015.com/portfolio-item/enhanced-biscuits-for-malnourished-children-in-africa/
- 2013: African Forum – 100 innovations pour un développement durable – Paris – 5 décembre 2013 catégory: *SAN – Bénin – Transformation des insectes comestibles,* (transformation of edible insects) https://hermannreports.mondoblog.org/2014/03/12/distinction-des-laureats-beninois-du-forum-afrique-pour-linnovation

Fig. 4.4 Different photographs of edible insects and preparations; (**a**–**b**) *Orytes* larva that have been grilled from man from Benin; and man come from Costa Rica fried *Orytes* larva's in rural locality in Benin (Photo credit: S. Tchibozo 2009); (**c**–**d**) The author on a field trip in East Benin. Palm weevil larva cooking in a pot cooking (Photo credit: R. Kok, Benin 2012); (**e**–**f**). Grilled orthoptera in West Benin (Photo credit: S. Tchibozo 2004 and 2012); (**g**) Cricket legs, whole termites, scrambled eggs and rice cooking by author (Photo credit: S. Tchibozo 2012); (**h**) Therapeutic consumption of a raw termites queen (Photo credit: S. Tchibozo 2003)

- 2012: First price in the competition 'Parlons développement durable!'(let us talk about sustainable development), catégory: 'Information Scientifique' (scientific information): Les insectes alimentaires de la République du Bénin (edible insects in the Benin Republic. French Embassy in Bénin, IFB, MEHU, MESRS, ORTB, RFI, etc. https://fr.horyou.com/member/severin-tchibozo-1/action/les-insectes-alimentaires-de-la-republique-du-benin

4.4.2 The Past and Present Project

- 2021–2023: Insects-food & Tour, https://www.reseau-ulysse.be/insects-food-tour. This project aim to promote the edible insects in Benin: by tourism together with the cooperation from researchers from Benin in Belgium.
- 2016–2018: Valuation for edible insects in the food. Concern the cricket breeding in Benin with two NGO. The first idea for this project come author and CRGB in 2015. The French NGO has fly and to develop with others local NGO in Benin. The aim is to breeding local insects and combat malnutrition in Benin.
- 2009–2012: The edible insects online in West and Central French Africa (Les insectes comestibles d'Afrique francophone de l'Ouest et du Centre sur Internet: LINCAOCNET), http://gbif.africamuseum.be/lincaocnet/https://biogov.uclouvain.be/Besafe-Biomot-Conference-June2015/posters/Tchibozo-Mergen-June%202015final.pdf
- 2008–2011: Collaboration between, Benin, Bhutan and Costa Rica in Sustainable Biodiversity Knowledge and Use. People, coming from Costa Rica, discover the edible insects in Benin and will promote them.

To outsiders it may seem unusual, but in Benin, insects are common snack. South-South cooperation is allowing Costa Rica to new experiences, https://www.youtube.com/watch?v=TQHq1kKRV_s.

4.5 Conclusion

Insect consumption belongs to traditional food culture for many different societies in the world. It is not only a matter of taste, but also a viable alternative for meat in the rural, peri-urban and urban areas. The breeding of potential edible insects and development of farming facilities is necessary for sustainable conservation. In 2050, there will be nearly 10 billion humans on earth, and the promotion of the consumption of insects could be a potential solution to feed people with animal proteins. Sustainable breeding or farming is strongly recommended to sustain consumption, as well as to preserve the natural ecosystems.

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Chapter 5
The Decline of Agrobiodiversity: Process of Crop Improvement, Consequent Homogenization, and Impacts

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Abbreviations

GM genetically modified
HYV high-yielding varieties

5.1 Introduction

Agricultural biodiversity or agrobiodiversity, in simple terms, implies the diversity in various ways, richness, evenness, or divergence, of edible flora and fauna. In other words, it is also invoked to refer to the vast number of varieties and variability of living organisms that not only contribute to food and agriculture but also to the knowledge associated with them (Thrupp 2000). In a more inclusive sense, agricultural biodiversity does not only encompass the various forms (varieties, breeds, species) of living organisms essential for food, fiber, fodder, fuel, and pharmaceuticals but also the larger adjoining ecosystems (agricultural, pastoral, forest, aquatic or fallow) that closely support their production. Therefore, it includes wild uncultivated edible (edible flora and fauna which are not under an organized cultivation regime) and non-edible species (numerous pollinators, millions of macro- and microbiota of soil), and other associated landscape elements (hedges, pastures, perennial and non-perennial aquatic bodies, marshes, fallow, etc.) that shelter them (FAO 1999). Also vital is the traditional agroecological knowledge of the farmers or associated key persons which is viewed as an indispensable component of the farming systems (Argumedo 2008; Koohafkan and Altieri 2011).

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It is the interplay of natural selection, random genetic drift, migration, and mutation that co-act with the creation of diversity; it was also shaped by the artificial human-mediated selection and cultivation by farmers and gatherers, herders and fishers who used to maintain and utilize that diversity over millennia (Frankel et al. 1995; Hancock 1992; Hufford et al. 2019). So, they remain at the center of agrobiodiversity creation and management, make use of them and garner a rich body of knowledge that imbibed key information about the know-how of employing and exploiting the specific properties of the cultivated or non-cultivated genetic materials. Thus, most farmers play an important role in the flow of genetic materials and in strengthening the on-farm conservation, diversity deployment, seed supply system, conservation, and training (Subedi et al. 2003). Globally, there has been a growing recognition of traditional knowledge systems and their potential role in tackling the climate crisis (Anon 2022; Forest Peoples Programme 2020). So, the notions of agricultural biodiversity tend to expand from a narrow delimitation of edible species diversity and embrace the larger systems with multiple components essential to sustain food and agriculture.

Agrobiodiversity is the bedrock of agricultural production that sustains, can improve human nutrition, and provide sources of medicines and vitamins. Decades of intensive research and analyses have demonstrated that agrobiodiversity has a key role in the functioning of ecological systems, conserving ecosystem structure, the generation of a vast array of services, rendering farming systems more stable and sustainable; and at the same time, it can intensify production causing less environmental harm, increase economic returns and support livelihood, and ensure food security (Barthelet al. 2013; Brookfield and Padoch 1994; Cromwell et al. 2001) It can help conserve soil, increase natural soil fertility and health, maximize the effective use of resources and reduce dependency on external inputs, and contribute to sound pest and disease management (Di Falco 2012; Thrupp 2000). In addition, it has also been increasingly evidenced that agricultural diversity reserves the potential to insulate the effects of climate change through adaptation and resilience (Kotschi 2006; Bellon 2008).

In the last two-three decades, there has been a plethora of studies reporting the general decline of agricultural biodiversity across the globe (Duvick 1984; Vellve 1993; Tripp 1996; Khoury et al. 2022; Fu 2006, 2015; Mir et al. 2012; Brush 1999; Brush et al. 1992; Hammer and Teklu 2008, but also see Montenegro de Wit 2016). A broad consensus is that the traditional landraces in the fields of farmers were largely replaced by modern or improved cultivars; so on-farm conservation of landraces has been greatly compromised (Brush et al. 1992; Hammer and Teklu 2008; Witcombe et al. 2011; Wood and Lenne 1997). There were macro-scale drivers at large including economic, agronomic, demographic, land-use, and other global environmental changes (Brookfield and Stocking 1999; Mwalukasa et al. 2002). Of all, one of the well-researched topics is the massive developmental program like the Green Revolution that geographically spanned three continents. It was actually implemented as a technological package to bolster the productivity of two staple cereals to render the country food secure. Though successful in raising the productivity of rice and wheat, it accelerated the erosion in cereal diversity, through the introduction and dissemination of modern varieties, the development and promotion of mega varieties, dismantling the agrarian systems, and forcing farmers to be dependent on external inputs and thus linking them to the market economy. However, the embryo of the Green Revolution that has assumed its demonic stature was implanted much before, perhaps with the emergence of plant breeding tools and technology, the creation of modern seeds, the growth of the seed sector, and the establishment of *ex situ* genebanks. The progress gained its inertia through rapid advancement in science and technology, especially crop improvement through plant breeding and global politics (Patel 2013). Concurrently, the political ecological context of their implementation has facilitated an irreversible and radical shift in agrarian activities. It, in turn, exerted its effect on agricultural biodiversity in many ways leading to its overall dwindling. However, the agrobiodiversity erosion at the country or continent level is far more recognized and well-described than its local dynamics. Specifically, how the larger global processes operated spatiotemporally at the local or regional level and caused gradual homogenization is inadequately understood.

Generally, the loss of diversity in cultivable forms usually measured in terms of certain markers (e.g., molecular markers) is often relatively discernable (Chakraborty and Ray 2019; Hammer et al. 2003; Ray et al. 2013). They offer insights into the loss in terms of the alleles, or other analogous measures of molecular diversity (Bayush and Berg 2007; Fu and Dong 2015; Fu and Somers 2009; Fu and Somers 2011; Martínez-Castillo et al. 2016; Martos et al. 2005; Van de Wouw et al. 2010a, b; Khoury et al. 2022). However, the ways of estimation of molecular diversity are often blind to the causal agencies, socio-cultural, economic, or demographic, underlying the loss of diversity. Therefore, the struggle to uncover the loss or change is often frustrated by limited information; for this reason, the investigation to unravel agrobiodiversity change turns out to be a simple exercise to estimate molecular diversity disabling to elucidate the big picture of change. Looking through the lens of Political ecology, the erosion of agrobiodiversity is not just situated within the domain of evolutionary biology or agricultural sciences but is perceived as rooted in historical and social processes (Blaikie 1985; Robbins 2019). It strives to untangle many ways in which political and economic interests shape agricultural development interventions. Therefore, political ecology tends to illuminate the larger picture operative against the backdrop of broad agrobiodiversity change. The changes that are not always directly detectable also capture key information, e.g., loss of acreage, introduction of modern cultivars, expansion of HYVs, extinction of certain landraces, etc. These also allow us to gain an indirect idea of the loss and drivers at large that are otherwise difficult to track down. Especially, the decline can occur in many different ways under the aegis of larger science and technological progress and intervention, developmental programs, socio-economic changes, cultural transition, etc., and analyzing the same is the main premise of the article. I would struggle to disentangle the various technological progress pertaining to breeding and improvement that led to agrobiodiversity erosion. In other words, by taking specific examples of crops, I would address the ‘how’ (did it happen) question. In doing so, a mixed approach will be employed and nearly all complementary measures detecting the change will be considered. For example, I gauge the introduction of modern varieties (the number of cultivars released in a period, etc), the replacement of traditional varieties or landraces, the increase in acreage under modern varieties or specific cultivars, the emergence of super- or mega-varieties, a specific program for crop improvement (for disease resistance or yield increment) and followed by the release of cultivars, monocropping and changing cropping pattern, and unusual rise in the acreage of certain crops at the cost of others (Brush et al. 1992; Hammer and Teklu 2008; Fu 2006, 2015; Fu and Dong 2015; Gao 2003). The idea is to capture the broad discernible changes in diversity and its socio-political or economic context of operation. Furthermore, I illustrate my points by dwelling on specific case studies on a variety of crops, rice, wheat, cotton, pearl millet, or pulses within the geography of India, however, some key crops will receive more focus than others owing to their status, importance to country's economy, data availability, etc.

5.2 The Global Agrarian Change

In traditional agroecosystems, genetically and phenotypically heterogeneous crop landraces have been cultivated in an assemblage of different crop species in a temporally and spatially diverse crop arrangement or cropping pattern; they are mostly managed with low externally procured inputs and family labor (Jarvis et al. 2008; Koohafkan and Altieri, 2011; Zeven 2002). This is in stark contrast with the vast swathes of modern crop fields performing monocultures of 'modern cultivars' developed through government- or private-funded projects and disseminated by private players or agricultural extension programs and supplemented with heavy inputs, i.e., agrochemicals, water, or power-driven machinery (Duvick 1984; Zhu et al. 2000). The imminent question arises: how did it happen? How was a majority of the traditional agroecosystems transformed into modern-day agricultural fields? The answer to the questions lies in the understanding of global agrarian change over the past two centuries. Furthermore, it has to be recognized that although the two extremes, traditional and modern, are broadly distinguished there exists a myriad of agroecosystems that fall in the continuum. In an increasingly globalized world, the divide between them has been blurred and in most cases, the traditional systems nowadays are intruded on by modern cultivars, energy-hungry irrigation systems, or external inputs. Generally, the diversity in traditional agroecosystems is managed through farmers' selection of random and novel mutations, their curation, and the cultivation of newer forms. It also encompasses various uncultivated edible or non-edible species and broader adjacent ecosystems. In traditional systems, the seed exchange often facilitates gene flow among landraces tapping and enhancing genetic variation, and continued cultivation and selection leading to local adaptation (Bellon 1996; Mercer and Perales 2010). Additionally, occasional introgression from crop wild relatives can also introduce novel variations (Jarvis and Hodgkin 2002). However, it will be untrue to say that traditional agroecosystems are completely geographically disjunct and farmers are averse to experimentation with newer varieties. On the contrary, they are keen to explore, innovate, and recurrently perform tests with newly arrived landraces to find out the suitability in their systems (Brush 2004; Chambers and Thrupp 1994; FAO 2014).

Historically, new crops and newer varieties were similarly traded, translocated, experimented with, and naturalized in the new geographic regions, sometimes across a larger continental distance, e.g., the great Columbian exchange was one of them but various crops were already traded and exchanged much before that, like the trans-Eurasian exchange of millets from Africa (Boivin et al. 2012), or African rice diffusion, etc. (Carney 2001). The cross-continental Silk routes were prominent land routes for quite a long time (Ray and Chakraborty 2021; Weatherford 2018; Spengler 2019). In a relatively recent period, for example, around the sixteenth or seventeenth century, enthusiasm to create newer varieties of vegetables or fruits was in full swing in Europe. Experiments were carried out, without knowing the underlying genetics, to produce vegetables or fruits of desired color, shape, or size (Kingsbury 2011). Another development in the agri-horticulture sector was also instrumental mostly in Europe. Until the seventeenth century, most seed saved by growers was sown in the following season with exchange and little trade. During the seventeenth and eighteenth centuries, a trade of seeds grew, particularly of fodder and ‘garden’ crops (i.e., vegetables), generally from the countries like Italy, France, and Switzerland to northern Europe. Other countries, Turkey and Syria, also contributed to this seed import (Kingsbury 2011).

Even though seeds of certain vegetables or fruits were packed and traded by some local producers in an organized manner, the scale of operation or the magnitude of the business was not big compared to today’s scenario. The actual change began to happen after the development of modern cultivars through the technology of plant breeding and its sweeping entry into the agricultural sector. It brings us to the context of global agrarian change, and the transformation of traditionally managed agricultural systems in tandem. The science of plant breeding was spearheaded by the rediscovery of Mendel’s laws of inheritance in the twentieth century which paved the path for the subsequent development of modern crop cultivars (Bateson 1904). It was a historic turn that not only allowed the scientists to exploit a new range of tools to investigate the biological world breaking into a smaller unit of the organization but also marked the beginning of the ‘metamorphosis’ of traditional agroecosystems. It enabled the material of regeneration, i.e., seeds, to be developed away from the agricultural fields by non-farmer scientists and subsequently distributed among the farmers. So, the technology of plant breeding has moved to research stations and performed by scientists, and gradually turned into a private-funded enterprise. As a consequence, not all crops were treated equally, and some became ‘orphan crops’, neglected by science, while economical crops won precedence (Ceccarelli 2009). The whole development thereby entirely reorganized the dimensions of the political ecology of agrarian activities (Clapp 2018; Howard 2015). Armed with the new technology, the plant breeders gradually garnered the power to exercise novel breeding methods to create newer types of agriculturally and economically important plants (Harwood 2016). There was a growing recognition of the value of landraces and their wild relatives (Zeven 1996, Zeven 1998) and the establishment of *ex situ* repositories or genebanks to preserve genetic materials for exploitation in breeding to create crops with desired traits like higher yield, greater pest and disease resistance, early maturity, greater biomass, etc. (Lehmann 1981; Saraiva 2013). It was set in motion by the global inertia to conserve diversity derived from landraces and crop wild relatives, away from fields, in the big genebanks (Fowler and Mooney 1991; Thrupp 2000). The initiative was accelerated by the alarms over the decline of crop diversity stemming from larger social, economic, or political changes (Harlan and Martini 1936; Samberg et al. 2013). So, the whole package of the technology of plant breeding, modern seeds, seed production laboratories, and *ex-situ* banks gradually began to operate to their capacity. It set loose the breeders to 'improve' crop species with their magic wand, thereby pitching an indomitable control over global agriculture through the formation of corporations (Clapp 2018; Hendrickson et al. 2017; Montenegro de Wit 2016). Some geopolitical regions were much ahead of others, especially the developed world from where the technology permeated to other regions. In the US, this was set in motion by the development of hybrid corn in 1930–40 (Kloppenburg 2005; Stone 2022). The socio-economic context to feed all was created by an urban population explosion that left no space for opening up new land for cultivation but to increase maize yield. The application of plant breeding techniques appeared to be a promising option (Duvick 2001). However, the concern over genetic erosion or loss of landraces surfaced with the mass propagation of plant breeding, at least in some parts of the world (Clapp 2018; Graddy 2013; Stone 2004).

In the late 1960s, the 'Green Revolution', a vehicle to lessen hunger in developing nations, foster economic growth, and secure political alliances, promoted new high-yielding cultivars and associated agronomic practices (Patel 2013; Ray 2022; Shah et al. 2021; Stone 2022; Subramanian 2015). It grossly accelerated the replacement of landraces and led to the destruction of the habitats of crop wild relatives (Pistorius 1997; Ray 2022). As a result, the notion of loss or genetic erosion received further attention, and the use of landraces was again felt to be essential in plant breeding (Frankel and Bennett 1970). Therefore, it remained at focus of any plant breeding or improvement program (Dwivedi et al. 2016). And, slowly, it opened the avenues to the formation and expansion of national and international institutions to collect, document, and maintain the genetic diversity of crops and their wild relatives in genebanks (Plucknett et al. 1987; Dempewolf et al. 2017; Fowler and Hodgkin 2004). The definition of agricultural diversity began to expand, recognize and include pollinators, landscapes, livestock, and non-crop species providing essential ecosystem services. It also embraced the significance of cultural diversity that has traditional agricultural knowledge at its core (Argumedo 2008; Koohafkan and Altieri 2011; Benz et al. 2000). The support for *in situ* or on-farm conservation gradually poured in to explore its role (Brush 2004; Brush and Meng 1998; Wood and Lenne 1997; Bellon 2004; Bellon 2008; Sthapit et al. 2001), though its efficacy was met with skepticism (Peres 2016).

Concomitant with the development was the rapid expansion of global seed industries and corporations that produced various agricultural inputs, mostly seeds and agrochemicals like fertilizers, pesticides, weedicides, etc. (Liu et al. 2015). The rise of industrial agriculture resulted in a fast increase in the use of inputs, mostly fertilizers, and pesticides, and thus the demand skyrocketed. In developing countries, it was promoted in the disguise of the Green Revolution (Ray and Chakraborty 2021; Ray 2022). On the one hand, the rise in pesticide use could be an outcome of the increased genetic homogeneity of crops nurtured in vast monocultures under intensified production systems (Altieri 2009); since genetic homogeneity tends to increase the vulnerability to pests or pathogens, which warrants chemical inputs to manage infestations (Andow 1983; Tilman 1999). On the other hand, the development of improved modern cultivars through breeding to take up fertilizers efficiently and produce the enhanced amount of grains rendered them dependent on mostly nitrogenous fertilizers, which led to a steady demand for fertilizers that went on rising ever since (Khush 2001; Liu et al. 2015; Heffer and Prud'homme 2016). And at the background, there were various mergers and mega-mergers of global corporations, a rise in their market share, and consolidation of their power to control world agriculture through the discovery and dissemination of technology in the form of seeds or chemicals, or mechanization (Clapp 2018; Clapp and Purugganan 2020; Hendrickson et al. 2017). However, the impacts of the broad changes at the global level on agricultural biodiversity may not be apparent but they continue to act towards homogenization through a multitude of proximal or distant drivers.

Responding to the rapid loss of the world's biological diversity, conservation, sustainable use, and equitable benefit sharing was prioritized through the Convention on Biological Diversity (CBD) in the 1990s (CBD 1992). After the CBD, the past agreements on the conservation of crop diversity were updated to accommodate the large framework, providing new avenues for collaboration through the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO 2002). In recent decades, the CBD, ITPGRFA, and Sustainable Development Goals (SDG) of the United Nations have formulated and mandated specific targets for safeguarding global agricultural diversity (CBD 2002, 2010; FAO 2002; United Nations 2015). It has been integrated into the major international agreements on biodiversity and human well-being and highlighted the importance and complementarity of both *ex situ* and *in situ* methods for crop genetic resource conservation (e.g. Ceccarelli 2009; Graddy 2013; Montenegro de Wit 2016; Samberg et al. 2013; Sthapit et al. 2001; Stenner et al. 2016).

5.3 The Indian Context of Agrarian Change and the Saga of Crop Improvement

The subcontinent could not feel the intense heat of the radical agrarian change taking place at the global level until the middle of the century. But, it does not imply that the attempts to improve the Indian agricultural systems were kept at bay, the colonial trials were already underway. In the late nineteenth century, repeated famines perhaps made the podium to reconsider the necessity of developing agricultural science in India. It further received a thrust by the Voelcker report which while praising the Government for irrigation facilities was critical of neglecting modern scientific approaches, especially manuring and yield increment (Arnold 2000; Voelcker 1983). But until the formation of the Indian Agricultural Research Station (later renamed Imperial Agricultural Research Institute), most of the initiatives remained in a rudimentary state. Moreover, the British mindset of pre-colonial Indian agriculture was based on the assumption that it was almost devoid of any meaningful scientific and technological tradition (Baber 1996). The repression of indigenous knowledge may not be because of their scientific faith or colonial bias, but to legitimize the affirmation of the state institutions and its agents (whether European or Indian) by the deskilling farmers (Preeti 2022).

To improve agricultural systems and increase productivity, an early attempt to introduce English wheat was criticized by Voelcker (1983). It was later substantiated by Albert Howard and Gabrielle Howard – the scientist duo who chose to examine the properties of three dozen different varieties of indigenous wheat. Subsequently, they developed rust-resistant hybrids that were well suited to the Indian conditions but superior in quality and market value to the existing crops (Arnold 2000). There was also the publication of the Royal Commission on Agriculture report which has been considered a major milestone in Indian agriculture as it objectivized seed sector development (Chauhan et al. 2017). Agricultural research in the country received further momentum from the Famine Enquiry Commission and Grow More Food Program Committee, which emphasized the need for quality seeds of improved varieties. Thereafter, many seed farms were established in community development blocks during the fifty's.

A major stride in agricultural research in India was pioneered by the inception of All India Coordinated Research Projects (AICRPs). The initial attempts to improve were made on maize in 1957 with the active collaboration of the Rockefeller Foundation and the first hybrid maize was released in 1961. Hybrid maize was followed by the release of the hybrids of sorghum and pearl-millet (Chauhan et al. 2017). Under the aegis of the program, the central research institutes, agricultural universities, and the State Departments of Agriculture were asked to work collaboratively to resolve the problems related to food security at the national level. Various coordinated programs on rice, wheat, maize, vegetables, fruits, and livestock were undertaken and have been executed in the last four-five decades (Chauhan et al. 2016a). Generally, the Indian programs, just like the global agricultural strategies, have been broadly aimed at the enhancement of yield, and improvement of other traits pertaining to adaptation, resistance to various biotic and abiotic stresses, and enhancing end-use qualities (Fu 2006, 2015; Mir et al. 2012). As a result, many modern varieties with higher yield (rice, wheat, pearl millet, cotton, etc), disease or pest resistance (e.g., various crops), short-duration (rice, wheat, pearl millet), or other desirable traits like specific staple length (e.g. cotton), cooking quality (wheat, rice), nutrient content (biofortified crops), or broader adaptability to grow in varied agro-ecological conditions (rice, wheat, maize, and many other crops) were released over the last decades (Anon 2017).

The application and wider dissemination of technology through the introduction, expansion, and establishment of modern cultivars are often flagged as harbingers of genetic erosion and homogenization (Fu 2006, 2015; Brush 1999; Hammer and Teklu 2008; Tripp 1996). They tend to have a long-standing and irreversible impact on agricultural biodiversity though this has not been systematically investigated in the Indian context or elsewhere. The improvement programs, for their highly specialized objective to enhance a narrow set of traits at a time, manipulate underlying gene(s), whereas the traits under improvement are often complex and polygenic, i.e., controlled by several genes (Heffner et al. 2009; Jansen 1996; Mitra 2001). In the process of developing new cultivars, they negatively influence the diversity of landraces or heirloom seeds that farmers have cultivated for various reasons, yield or disease resistance may not be the exclusive reasons. So, the entire exercise of valuing diversity, other than the desired ones, has been undermined. Although there has been a lot of concerns over the loss or decline globally, very little is known about the actual process operating on the ground. And, also not known is how its progress set in motion by the steps in the improvement programs which unequivocally replaced landraces with modern or improved or elite varieties in many different ways. Thus, I reiterate that I would address the 'how' (did it happen) question and develop my argument by citing examples of various crops and their trajectory of improvement over time.

5.3.1 Replacement of Traditional Varieties or Landraces – the Role of the Green Revolution

One of the better-known ways leading to the erosion of diversity is through the replacement of traditional varieties or landraces and the most well-documented case in India stems from rice. It is because rice being the primary cereal holds the highest stake in acreage and inevitably its history has been examined in greater detail. In the last seventy years, rice landraces have dwindled to a great extent. For example, an estimate says approximately 15,000 landraces of rice had been cultivated in undivided Bengal in the 1940s. The recorded number of landraces cultivated in West Bengal just before the 70s was little more than five and half thousand (Deb 2021). The Green Revolution and its extension activities have taken deep roots since 1970 and radically transformed Indian agriculture (Nelson et al. 2019; Shah et al. 2021). A few stout, short-stemmed, bushy semi-dwarf high-yielding varieties (HYVs) gradually substituted many traditional landraces of eastern, southeastern, and southern India at the outset. Later, many modern cultivars were developed responding to local agroecological requirements and it helped to expand the acreage under a few selected and successful HYVs (Pathak et al. 2019; Ray 2022). However, in the longer run , the spread and high acceptance of only a few modern HYVs like Swarna, MTU 1010, IR 36, Satabdi, etc further exacerbated the homogenization. Although the case of rice is more pronounced than any other crop many of the staples and non-staples experienced a similar loss of traditional varieties.

Wheat, India's second most important cereal, that has also been included in the Green Revolution package. The replacement of wheat landraces occurred almost the same way. Before the Green Revolution, most Indian varieties were tall with weak stems considered high in disease-susceptibility, high biological yield, low harvest index, longer vegetative and shorter reproductive period, and thus were not fit for intensive agriculture with external inputs (Joshi et al. 2007). To bolster wheat production, the semi-dwarf varieties were introduced from CIMMYT, Mexico (Kulshrestha and Jain 1982). It has been observed that by the late 1990s the semi-dwarf varieties covered over 80% of the wheat areas of all developing countries with adoption rates of 90% or more in South Asia (Byerlee and Moya 1993). From the beginning, many varieties adapted to different agroecological zones of India and neighboring countries (e.g., Nepal and Bangladesh) were released gradually (Evenson et al. 1999). They eventually succeeded in replacing numerous landraces cultivated in the wheat-growing zones of south Asia. Being major staple, wheat has been under a continuous process of varietal improvement. The developed varieties were one of the technologies that quickly diffused among the farmers during the Green Revolution period and later. Consequently, only a tiny area in the wheat-growing states of Haryana, Uttar Pradesh, Punjab, Bihar, Madhya Pradesh, and Rajasthan is currently under the traditional varieties or landraces. Broadly, such a trend is predictable as Haryana and Punjab have been the epicenters of the Green Revolution (Pavithra et al. 2017). Although the high-yielding semi-dwarf varieties under the flagship project of the Green Revolution worsened the process of decline, the erosion of landraces had begun quite earlier than that when crop breeding to develop modern varieties was underway in parts of India and the development of rust-resistant 'Pusa hybrids' were a few examples (Arnold 2000).

5.3.2 The Emergence of Hybrids

Successful production of crop hybrids and exploitation of hybrid vigor lay the foundations of a new era of plant breeding and crop improvement. Although the creation of hybrid rice for high-yield potential commenced quite later, a few other staples underwent the course of experimentation and led to the successful hybrid formation. In 1961, the first hybrid of maize or corn was released and it was soon accompanied by sorghum and pearl millet. Hybrid pearl millet was one of the first hybrid crops in the world and was released by the public sector institution in India in 1965. It was in contrast to the Green Revolution cultivars which were improved varieties of rice and wheat rather than hybrids.

Pearl millet or *bajra* is the third most widely cultivated staple crop after rice and wheat and has been grown on nearly nine million hectares. Being a cross-pollinated crop with high (approx. 85%) outcrossing rates pearl millet displays a high degree of heterosis for grain and stover yields (Burton 1983). The genetic improvement started in the 1930s to improve yield by mass selection and progeny testing, which led to the development of some open-pollinated varieties (OPVs). Since those OPVs were developed from a limited number of landraces, they provided minor improvements in actual yields. The major thrust for the development of OPVs began in the 1970s with the establishment of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The programs exploited a range of African germplasms and disseminated a diverse range of breeding materials. A diverse range of gene pools, populations, trait-based composites, and OPVs using germplasm originating in Africa and/or Asia was developed gradually till the late 1980s (Rai and Kumar 1994). The pearl millet hybrid era kicked off with the introduction of the male-sterile line, Tift 23A, into India from Georgia, USA in 1962. Five hybrids based on this line were released during 1965–69. The major thrust in pearl millet was to improve yield potential in fragile arid regions (Yadav and Rai 2013). After the release of the first pearl millet hybrid, the acreage under hybrids increased rapidly owing to higher yield. The spread of pearl millet single cross hybrids and their impact on production and productivity has been higher in regions equipped with better production environments. However, there has been limited adoption of hybrids in the arid zone due to their poor adaptation. Indian landraces were sources of early maturity, better tillering, and shorter height, whereas the landraces from Africa provided sources for larger head volume and seed size, higher degrees of resistance to diseases, and better seed quality. While the pre-hybrid era mostly relied on OPV and traditional varieties, the first hybrid era (1966–1980) witnessed the dominance of a few hybrids (17) and downy mildew disease was common. In the two subsequent phases from 1981, an increasingly large number of hybrids with genetically diverse parental lines was developed, and downy mildew was largely contained. It was followed by the use of highly diverse seed and pollinator parents and targeting broad niche adaptation (Yadav and Rai 2013). The high-yielding hybrids and OPVs have been widely adopted by Indian farmers and consequently, the area under improved cultivars has gradually increased over the years. Currently, a few improved OPVs and nearly eighty hybrids hold about 65% of the pearl millet acreage. Although the adoption of modern cultivars has been geographically patchy Haryana and Gujarat are the two top states in this regard (Yadav and Rai 2013).

Similar history of a widely grown pulse, pigeon pea, has been documented. Pigeon Pea is the second most important pulse in terms of acreage. The subcontinent is its center of domestication (Fuller 2011). The first variety of pigeon pea was developed by selection from a collection of wilt-resistant landraces (Shaw 1933, 1936). The scientific breeding effort progressed with the morphological and agronomic characterization of several elite pigeon pea field collections. It was followed by the identification of early and late maturing high-yielding types (Shaw 1933, 1936; Saxena 2008). Although the crop improvement activities by assessing field collections continued for nearly two decades they could not exert any significant impact on productivity. It began to gather motion with the All India Coordinated Pigeonpea Improvement Project in 1965 which applied the necessary impetus. Subsequently, nearly a hundred pure line varieties were released over the last 70 years resulting in substantial increases in production areas (Ryan 1997; Singh et al. 2005).

Between 1980 and 2000, various disease-resistant varieties were developed and the effort culminated in a number of hybrid development from the new millennium (e.g., ICP 8863, ICPL 87119, ICPL 332, ICPL 84031, ICPL 151, ICPL 88039, etc). For example, ICPL 87119 (Asha) is a wilt and sterility mosaic disease-resistant variety widely popular in the country and today occupies the largest area. So far, ICRISAT in active collaboration with various universities, institutes, and government bodies has released many hybrids (like ICPH 2671 and ICPH 2740). These hybrids have recorded a 30 to 40% yield advantage over farmers' varieties (Sameer Kumar et al. 2014). Although the specific cases of pigeon pea, pearl millet, hybrid rice, or cotton exemplify the integration of hybrids in agriculture, many more crops were brought under this technology in general and improved varieties diffused with varying success.

5.3.3 Introduction and Dominance of Mega-Varieties

Sometimes, the release of certain varieties developed through a long process of selection and breeding and disseminated across a large geographic region often marked a breakthrough in the history of crop science. The varieties subsequently received huge acceptance among farmers as well as consumers for higher yield, early maturation or multiple-disease resistance properties, better cooking qualities, etc. These mega-varieties still continue to be planted in a large acreage globally. Yet the examples from the other crops is less but the case has been well evidenced in the case of rice cultivar IR 36 or IR 64 (Mackill and Khush 2018).

International Rice Research Institute initiated the development of various improved cultivars through the rice crosses made at IRRI and they were assigned a number with IR (international rice) as a prefix. The first cross made in 1962 was named IR1 and the subsequent crosses were given consecutive numbers. IR8 was the variety developed in 1966 and was selected from the eighth cross made in 1962. Although known for very high grain yield IR8 had poor grain quality, lack of disease and insect resistance, and late maturity. Therefore, the attempts over the next two decades were made to develop varieties to improve greatly on these traits (Khush 1999). In early 1980, one of the most popular varieties grown was IR36 since it was resistant to disease and insects. Also, it demonstrated a higher yield within a shorter period of 111 days (from seed to seed) compared to IR8 (130 days) (Khush and Virk 2005). Eventually, it was fast accepted and was estimated to be planted on more than ten million hectare (ha) during the 1980s. While these early-generation IR varieties offered good productivity they still lacked the desired cooking quality (e.g., intermediate amylose content, gelatinization temperature, etc) of the pre-Green Revolution varieties grown in the Philippines and Indonesia. IR64, the coveted miracle rice, released in the Philippines in 1985, was a major breakthrough in combining the better palatability of cooked rice with a higher yield, disease resistance, etc. IR64 soon replaced IR36 in most growing areas and spread rapidly in newer areas. By 1995, IR64 has been successfully grown in eight million ha (Khush 1995). The wider acceptance and longer persistence of IR64 in farmers' fields were attributed to its excellent cooking quality (Champagne et al. 2010). Because of its relatively wide adaptation, early maturity, and improved quality, it gradually became popular and provided hundreds of millions of consumers with high-quality rice. Once, it was grown on 9–10 million ha annually (Laird and Kate 1999). Apart from the Philippines and Indonesia, it is also widely grown in India. During 1998–2006, IR64 alone accounted for over 10% of the breeder seed produced in India. It was still above 3% in 2015 meaning it was grown on 2–3 million ha annually. In the Philippines, the area of production of IR64 declined during 2000–2007 and was substituted by newer varieties, mainly due to its susceptibility to tungro disease. It has also given rise to the next-generation IR varieties. In India, the variety MTU 1010 became very popular, and it was derived from a cross between Krishnaveni and IR64 (Mackill and Khush 2018). Unlike the Philippines and Indonesia where the new varieties have replaced IR64, it is still popular in India. However, there are other mega varieties like *Swarna*, MTU 1010, and *Samba Mahsuri* that were released and spread across India. There were a few others that gained acceptance regionally (*Shatabdi, Khitish, Pankaj, etc*) over the large rice-cultivating zones (Ray 2022).

Although the term mega-variety has not been tagged to any specific wheat variety, two varieties, HD 2967 and PBW 343 have emerged as mega-varieties in terms of the large share of acreage in India. The wheat variety, HD 2967, released in the year 2011, emerged as the most popular accounting for 11% of the total gross wheat cultivated area in six states (Haryana, Uttar Pradesh Punjab, Bihar, Madhya Pradesh, and Rajasthan). Whereas the wheat variety, PBW 343, was also spread in all six states covering about 9.5% of the gross cropped area (Joshi et al. 2007; Pavithra et al. 2017). Large acreage held by mega-varieties of crops implied extreme monocultures of rice or wheat hinging on very few varieties. It eventually steers to gross genetic homogenization and the loss of diversity.

5.3.4 Not So Mega-Varieties but Few Popular Cultivars with a Large Share of Acreage

While very few mega-varieties like IR64 or HD2967 or their derivatives dominated the disproportionately huge chunks of agricultural fields of India or elsewhere for a period of time, there was another set of modern cultivars that also encompassed moderately large acreage. The large acreage held by a few varieties has been documented and evidenced in rice and wheat, perhaps owing to the wider success and acceptance of a small number of the Green Revolution varieties. Among the vegetable crops, the case of potato is well-documented.

In the past forty years, more than three hundred wheat varieties were released in India's six wheat-growing zones and this played a key role in increasing wheat productivity (Chatrath et al. 2006). It has been observed that although sixty cultivars have been cultivated in different zones, most acreage has been held by only a limited number of cultivars (Nagarajan 2005). For example, one of the widely-grown varieties, PBW 343, occupies around six million hectares (Joshi et al. 2007) whereas, in the North Eastern Plains Zone (NEPZ), HUW 234 has been the most abundant covering around 2–3 million hectares (Joshi et al. 2007). Similarly, in central India, an old variety, LOK 1 (released in the year 1982) is the most cultivated variety (Anonymous 2003). Echoing a similar pattern, a study to evaluate the spatiotemporal spread of modern wheat cultivars in the top five wheat-growing states of India (Haryana, Uttar Pradesh, Punjab, Bihar, Madhya Pradesh, and Rajasthan) found that the large acreage held by only a small number of varieties, HD 2967, PBW 343, PBW 550, Lok 1, PBW 502. Of these, HD 2967 and PBW 343 are the top two wheat cultivars and covered 11% and 9.5% of the area share in 2013–14 (Pavithra et al. 2017). When wheat acreage under modern cultivars is broken down state-wise, we obtain further insights into the extent of concentration of the top varieties in five states. The gross wheat area of a state covered by the top five cultivars varied widely from 88.7% in Punjab to 42.9% in Uttar Pradesh. More or less 80% area is held by only five cultivars in Haryana (79.05%), Bihar (80.75%), and Punjab (88.66%) which portrays an acute case of genetic homogenization. Even in the states with the least acreage by modern cultivars, Uttar Pradesh, Madhya Pradesh, and Rajasthan, the percentage is no less in magnitude (42.9–60.9)%. A few of the cultivars, e.g., HD 2967, the most popular in Punjab, covered about 57% of the acreage while it occupied 14.5% in Haryana. Single variety occupying a large area has been reported earlier; C5912, in 1955, occupied nearly 80% of the wheat area in Punjab (Pal 1966). Similarly, another popular variety, PBW 343, in Bihar, Haryana, and Uttar Pradesh encompassed 30%, 20.2%, and 14.7%, respectively (Pavithra et al. 2017).

The story of rice following the Green Revolution reiterates the same trend. The early phase of the Green Revolution began in 1964 when Taichung Native 1 (TN-1) was imported to India. Later, several other HYVs (*Akashi, Bala, Cauvery, IR20, Jagannath, Jamuna, Jaya, Krishna, Pankaj, Prakash, Ratna, Sabarmati, Sona*) were experimented with till 1982–83 and the area under HYV in India grew steadily from a minuscule of 2.5% in 1966–67 to almost fifty percent in 1982–83 (Dalrymple 1986). However, the success of an HYV and its acceptance differed widely among the cultural geographic regions. For example, in West Bengal and a few other adjoining states, around 25–30 high-yielding rice varieties, e.g., *Shatabdi, Khitish, Gotra Bidhan* 1, IR 36, IR 64, *Lalat, Ratna,* MTU 1010, etc. were popularly grown during *boro* season under completely irrigated conditions. Of which, *Shatabdi* (11%)*, Khitish* (6%)*,* IR 36 (6%), MTU 1010 (6%), *Lalat* dominated the *boro* cultivation all over the state (Adhikari et al. 2011; Pandey et al. 2015). Similarly in *aman* season, out of sixty HYVs a few like *Swarna, Pankaj, Ranjit, Sashi, Samba Mahsuri, Mahsuri, Sabita, Hanseshwari,* etc. covered more than half of the total cultivated area. *Swarna* alone encompassed 43% of the area (Pandey et al. 2015). It implied a serious narrowing of the genetic base of rice since most of them are genealogically derivatives of either TN1 (a semi-dwarf variety from dwarf *Chow-wu-gen* and *Tsai-Yuan-Chunj*) or IR8 (a cross between high-yielding *Peta* and Taiwanese dwarf variety *Dee-geo-woo-gen*) (Pande and Seetharaman 1980) and more or less genetically homogenous. Further acceptance of even fewer HYVs based on their actual performance in the field resulted in an extreme narrowing of diversity. Although newer cultivars were developed in the succeeding decades diversifying the parental gene pool (Pingali 2017), *Swarna* and a few others still overwhelm the eastern Indian rice fields.

The story of potato cultivation also portrays the same trend (Pradel et al. 2019; Gatto et al. 2018). Only three cultivars, Kufri Pukhraj (released in 1998), Kufri Jyoti (released in 1968), and Kufri Bahar (released in 1980), covering 71% of the country's potato growing area is shared by Assam, Bihar, Madhya Pradesh, Punjab, Gujarat, Uttar Pradesh, and West Bengal. Kufri Pukhraj, a high-yielding and early-maturing variety, has been the most common variety covering 33% of the total potato area in 2015. It is the most abundant variety in Punjab, Gujarat, and Bihar and the second most abundant in Uttar Pradesh and West Bengal. Kufri Jyoti stands second in potato acreage (21% of the area) in 2015. It has been the dominant variety in Karnataka and West Bengal in 2015 and the second most important in Punjab. It is still preferred for good storability, tuber size, and a slow degeneration rate despite increasing susceptibility to late blight and lower yield compared to Kufri Pukhraj (Kumar et al., 2014). Kufri Bahar is the third most common potato cultivar which covers 17% of the potato area. It is the most popular in Uttar Pradesh but it is susceptible to late blight and produces moderate yield. Alongside survives *Bhura Aloo*, a native variety, particularly in Bihar. It has been cultivated for its red skin regardless of low productivity and late blight susceptibility since farmers prefer red-skinned potatoes for their higher market value, just like Kufri Sindhuri and Lal Gulal.

Replacement or the crowding-out effect is a common phenomenon that has been documented in many other crops. In this realm, other 'not-so-superior' varieties are eventually substituted by the choice driven by the acceptance of superior varieties. The superior variety could be a variety of the crop that fetches a premium price, is exportable, has better acceptance in terms of taste, etc. There are many examples, the replacement of a wide diversity of quinoa landraces in Bolivia with the internationally popular white and red types (Bioversity International 2013; Drucker et al. 2013). A near similar case was observed in several basmati landraces with different sizes that have been cultivated for generations. Owing to the narrow size specification of basmati for geographic indicator tag, thereby facilitating export has had an unintended impact on the local diversity of basmati landraces that once existed in the core cultivation zones (Osterhoudt et al. 2020). Another example can be sought from mango, the replacement of a wide range of old mango varieties with the popular and geographic indication-protected variety *Dashehari* has occurred in Uttar Pradesh (Rajan et al. 2016).

5.3.5 Changing Cropping Pattern

The decline of autumn rice, known variously as *aus, ahu*, or *bhadai*, illustrates an example of how the introduction and adoption of the Green Revolution HYV can change the cropping pattern and lead to a near-loss of a group of indigenous rice.

Pre-monsoonal upland rice or autumn rice has been cultivated in the relatively higher lands of the Indian subcontinent for centuries (Ray and Ray 2018; Chakraborty and Ray 2019; Ray In Press-a, 2023, 2022). It was an upland crop generally cultivated with relatively little water and generally broadcast in the drier months of March or April when occasional mild rains used to moisten the soil. It used to survive under mild water-limiting conditions of May. In the early monsoon in June, it matures followed by harvest in autumn between July and September (Ray In Press-a, 2023, 2022). This moderate-yielding rice was grown on relatively higher lands where cultivation of the rainfed transplanted *aman* has not been possible. Extended Bengal (that included Assam, Orissa, Bihar, and modern-day Bangladesh) has had a rich tradition of autumn rice cultivation (Allen 1905; Hunter 1876a, b; Vas 1911; Marshall 2006). It remained the second most important rice crop, next to *aman* or monsoonal rice, in Bengal and the eastern part of India. However, with the firm establishment of HYVs, especially the rising popularity of *boro* or summer rice, a gradual disappearance of *aus* or autumn rice has been observed. Many *aus*-growing districts with no to little *boro* acreage in 1946–47 switched to nearly 40% of their rice acreage to *boro* cultivation in 2014–15. In West Bengal, the *aus* acreage has shrunk to almost half whereas *boro* skyrocketed over a period of seventy years (from 10.2 thousand hectares in 1946–47 to 1271.72 thousand hectares in 2019–20) (Ray 2022). Neighboring Bangladesh has also demonstrated a similar phenomenon of technology adoption, from 1969–71 to 2006–08, the area under *aus* cultivation contracted from 3.24 to 0.96 million hectares and *boro* rice increased from 0.89 to 4.4 million hectares (Hossain 2010; Biswas 2017). The change in cropping patterns ignored the underlying agroecology of rice cultivation. In the past, *boro* was grown in winter in low-lying flood-prone areas after flood water receded. But the combined package of new HYV seeds, fertilizers, and groundwater has ensured its higher productivity; it offered a higher dividend that helped *boro* (or the Green Revolution in eastern India in general) to gain acceptance and eventually lead to the decline of *aus* diversity. It also brought in other changes alongside. Rice-wheat cropping system promoted through the Green Revolution also caused the shrinkage of coarse cereals, pulses, oilseeds, fruits, and vegetables in some states of the Indo-Gangetic plains and around (Ray et al. 2021; Singh 2000), though the magnitude of this change or its impact on diversity has not been well-examined.

5.3.6 Promotion of Cultivars with Specific Qualities

In some cases, the demand for specific characteristics of crops encouraged some cultivars to win farmers' choice, e.g., cotton cultivation in the subcontinent. It illustrates a case of how the historical trajectory of cash crop cultivation has undulated with the state apparatus, trade, taxation, policies, and technology diffusion (Flachs 2019; Menon and Uzramma 2017; Stone 2007, 2011). Two indigenous species were domesticated (*Gossypium arboreum*) or naturalized (*G. herbaceum*) in the subcontinent and profusely cultivated for thousands of years (Menon and Uzramma 2017;

Wendel et al. 1989). They produced elegant fiber of short-staple length that was fed to the local weaving facility for making the desired textiles. The industrial suitability of long-staples had facilitated the acceptance of exotic species followed by the gradual alienation of indigenous species. The seed of decline germinated a couple of centuries ago but the last sixty-seventy years experienced an intense wave of change. The erosion commenced in the early phases of tetraploid cotton introduction, expansion, and subsequent patchy cultivation in the eighteenth and nineteenth centuries. It amplified with the advent of the twentieth century through the introduction of hybrid cotton followed by Bt cotton hybrids and continued at an undiminished pace. Therefore, the long process of genetic erosion in cotton seems to be well rooted in history and multi-phased in its development.

In the early phase, two tetraploid species (*Gossypium barbadense, G. hirsutum*) were introduced in the late seventeenth century. At the outset, the two species were restricted and acreage was minuscule compared to the indigenous species until the early twentieth century. Despite vulnerability to pests, extreme heat, etc., the trials were in full swing owing to long-staple length. The socio-political changes taking place in the subcontinent greatly affected desi cotton; for example, industrial ginning was rapidly replacing hand ginning and their demand for long-staple varieties suited to the new machine was rising. Most of the indigenous varieties were of shorter-staple length and were unfit for ginning in industrial looms. Additionally, the discriminatory taxation and other policies imposed by the then ruling British administration discouraged Indian textile production (Menon and Uzramma 2017). Consequently, the acceptance of introduced species gained as the demand for a longer staple continued to surge. In the intermediate phase (1900–1970), acreage began to rise from the early twentieth century and it gathered momentum after the middle of twentieth century. By 1946–47, *G. hirsutum* was, however, only restricted to 3% of acreage while *G. arboreum* and *G. herbaceum* occupied 65% and 32%, respectively (Boopathi and Hoffmann 2016). Between 1970–71 and 2013–14, the acreage of *G. hirsutum* soared gradually to 42% and 91%, respectively. It was likely that the increment in acreage gained its inertia from the establishment of the Central Institute of Cotton Research and a country-wide improvement program in the early twentieth century. In tandem, the episode of the decline of cotton landraces continued. In the penultimate phase, after the introduction of the first *hirsutum* x *hirsutum* hybrid in 1970, the area under indigenous species continued to shrink rapidly. It followed the release of various intra- and interspecific hybrids for commercial cultivation (Singh and Kairon 2001). Moreover, the objective was to generate and release higher-yielding, improved fiber (long and superior-medium staple length), and short-duration varieties. The proclaimed 'high-quality' and homogenous new cultivars raised through breeding widely spread and further marginalized the use of indigenous cotton. As a result, *G. arboreum* and *G. herbaceum* retained the shares of 17% and 13% of the acreage in 1989–90. Also, the varieties of *G. barbadense* were reduced to a mere 0.3% of the acreage (Boopathi and Hoffmann 2016). Essentially, the outcome was mostly high-yield varieties of *G. hirsutum* grown in input-intensive monocultures. The final phase earmarked the introduction of Bt-cotton, a genetically modified variety developed from *G. hirsutum* hybrids, in

2002. The situation worsened further (Gutierrez 2018; Gutierrez et al. 2015). It was adopted by cotton farmers and is grown in nearly 90% of Indian cotton fields nowadays. The genetic constitution of cotton today in India comprises *G. hirsutum* (*hirsutum x hirsutum* Bt cotton hybrids) and it is represented by a few commercial varieties with a specific and narrow range of fiber, i.e., superior medium and long-staple. Moreover, Bt hybrids swept out many popular cotton varieties, AKA 7, AKA 8, GCot 11, GCot 13, LRK 516, MCU 5, SVPR 2, PA 225, RG 8, Sahana, and Surabhi, etc. which were once cultivated even in the marginal conditions. The production of extra-long-staple has also dwindled largely due to the replacement with superior-medium and long-staple cultivars. The acreage under *hirsutum x barbadense* Bt-hybrids remained tiny compared to *hirsutum x hirsutum* Bt-hybrids (Boopathi and Hoffmann 2016). As a result, the widespread adoption of Bt cotton has led to a recent bottleneck and extreme narrowing of the cotton genetic base.

5.4 Unwarranted Impacts of Biofortified Crops on Agrobiodiversity

The development, dissemination, and acceptance of crop cultivars with specific qualities like higher yield, disease or pest resistance, short maturation time, better storability, etc. have had a long-standing consequence on crop diversity. This has been clearly demonstrated by hybrid and Bt cotton. The recent phenomenon of biofortification or the production of nutrient-enriched crops also falls in this line. Biofortification is the process of increasing the density of micronutrients in widely-consumed crops either through traditional plant breeding, agronomic practices, or genetic modification (Bouis and Saltzman 2017). It aims to increase crops' content of iron, zinc, vitamin A or other micronutrients to improve nutrition and health; more specifically, these crops are claimed to mitigate hidden hunger that has been plaguing millions of people around the world now (Potrykus 2010). The meticulous attempts by Indian scientists to develop biofortified crop cultivars are not lagging behind.

Indian Council of Agricultural Research (ICAR) has embarked on improving the nutritional quality of high-yielding varieties of cereals, pulses, oilseeds, vegetables as well as fruits using breeding methods. During the 12th Plan, a special project on the Consortium Research Platform on Biofortification has been launched. The concerted efforts from the collaboration with other national and international initiatives have led to the development of 71 varieties of key crops. Among them are multiple varieties (more than three) of rice, wheat, maize, pearl millet, finger millet, mustard, and soybean. In addition, one variety of linseed, cauliflower, pomegranate, and more than one variety of lentils, groundnut, potato, sweet potato, and greater yam have been developed. A large number of elite materials are awaited to be released over the years and special efforts have been channelized to popularize them among the common people. The mega-project claimed to assume great significance to achieve the nutritional security of the country (PTI 2021). Quality seeds were produced and disseminated for commercial cultivation. The Extension Division of ICAR has been instrumental in launching two special programs, e.g., Nutri-sensitive Agricultural Resources and Innovations (NARI) and Value Addition and Technology Incubation Centres in Agriculture (VATICA) to upscale these varieties through various Krishi Vigyan Kendras (KVKs) (Yadava et al. 2020). Although genetically modified organisms have not yet been introduced through biofortified crops into India, GM rice or vitamin A-enriched golden rice cultivation has started in the Philippines, and Bangladesh is perhaps following in the footsteps (Ahmad 2022).

A seemingly humanitarian 'science for social welfare' project to end the world malnutrition problem can give rise to many detrimental effects on the social, economic, and cultural lives of the people (Ray 2021; Ray and Ray 2022). The putative impact on agrobiodiversity cannot be ignored. Many commentators have hypothesized the process of genetic erosion will inevitably be exacerbated by the introduction of such varieties in many different ways (GRAIN 2019; Ray 2021; Ray and Ray 2022). They argued that the cultivation of biofortified crops would encourage monoculture instead of diversified cropping systems. Importantly, the impacts of biofortified crops on indigenous biodiversity can be severe since the targeted regions of Asia, Africa, and South America are the centers of diversity or secondary centers of domestication of many crops. Earlier, a significant portion of diversity has been lost through HYV crops promoted via the Green Revolution. A similar process might work in the case of these crop cultivars. The special traits of these 'high-value' varieties might help them win farmers' choices driven by the market. It could happen through the higher demand created and elevated among the public for a particular 'high-value' variety; consequently, the farmers might be rewarded by growing the cultivars that would fetch an ensured better price and eventually will slowly shift to cultivating these cultivars only. There are worrying cases of promoting biofortified crops disregarding the diversity of nutritious and resilient local cereals and vegetables. The varieties also tend to disrupt local networks to restore underutilized or orphan crops (GRAIN 2019). Closely linked with the indigenous crop diversity is the case of seeds and food sovereignty that might be imperiled by the mass adoption of biofortified crops (Garcia-Casal et al. 2017). Whereas enormous edible floral diversity have been regarded as a reservoir of micronutrients that may hold the potential to reverse problems of hidden hunger (Cantwell-Jones et al. 2022; Ray et al. 2020; Ray and Ray 2022).

5.5 Drivers of Change in Agrobiodiversity: Yield Enhancement and Others

Intensification of production has not only been a demand of the nineteenth or twentieth century, but it gained its pace earlier in history when peasants intended to enhance their production, by choosing better-suited varieties, increasing cropping intensity, making judicious use of monsoonal rain, provisioning irrigation facilities, proper manuring, and exploiting certain fertile landscapes (e.g., river banks, flood-beds) (Fisher 2018; Habib 1963). The state intervened in these activities by providing corpus funding or channelizing the labor force for major irrigation canals, dams, digging water tanks adjoining temple-linked lands, irrigation channels, exploiting nearby temporary wetlands, and inundation from the seasonal floods (Krishna and Morrison 2009; Morrison, 2019). All of which, together or in isolation, facilitated intensified production of crops, that perhaps varied in success; some geographic regions were well-off enough to offer more than others (Fisher 2018; Ray In Press-a; Habib 1963). In other words, intensification was not possible everywhere but in certain geographies endowed with fertile soil, rainfall or irrigation facility, available labor force, etc. Also, with the increasing urbanization more land was brought under cultivation, by deforestation, reducing fallow, turning pasture, or grazing land into use that either enabled higher production or moderate production with less labor and money through extensification (Parthasarathi 2001; Ray In Press-a). In tandem with the growing food demand or increased taxation, fertile lands were cultivated twice or even thrice per year, i.e., higher production was achieved not only through increased yield or productivity from the same land but also by increased cropping intensity, e.g., double or triple cropping instead of single cropping (Fisher 2018). So, the trend to obtain more from the same piece of land has driven the peasants since the historical period and the saga continued responding to various social or economic stimuli.

However, the spatial scale and magnitude of intensified production have not been so wide and high prior to the modern-day crop improvement programs that explicitly hinged on the objective to boost crop yield. As economists argued that the agricultural output (all crops together) grew at a rate of around 3.2% per annum during the period 1949–50 to 1977–78. When decomposed, the growth rate of food grains and non-food crops was 3.19% and 3.22% per annum, respectively (Srinivasan 1979). These numbers are several times higher than 0.37%, 0.11%, and 1.31% per annum growth rates respectively for all crops, foodgrains, and non-food crops during the period 1892–1947 in then British India (Blynn 1961). In the following years, during the 1980s and early 1990s, agricultural growth was significant as evidenced by the performance of the crops, livestock, and fisheries sectors. The crop sector showed modest but still substantial growth during the early 1990s (Singh and Pal 2010).

Although it cannot be denied that various crop traits, viral, bacterial, or fungal diseases (smut, rust, blight, etc.) or pest (plant hoppers, mealybugs, borers, bollworms, etc.) resistance, early maturation, wider adaptability, better eating and cooking quality, were the key factors that have largely shaped the aims of the improvement programs, the enhancement of yield has always been the primary focus. At the country level, all cumulatively contributed to intensified production as India had a little extra land to be cleared for agriculture after 1960, the Green Revolution episode. Before that, agricultural expansion at the expense of forests was the key contributor to landuse landcover change and the process continued until the 1960s (Roy et al. 2015). The spurt in yield has reached a great magnitude in the last fifty-sixty

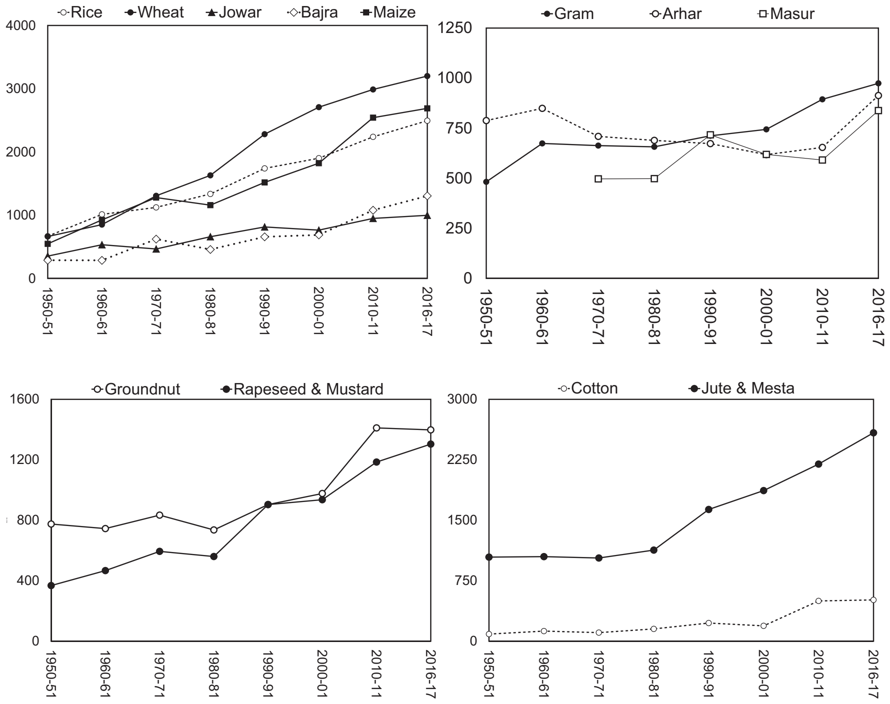

Fig. 5.1 The increment in yield (kg/hectare) of major food and fibre crops in the last sixty-seventy years period [Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India]

years, be it staple cereals, pulses, oilseeds, or fibers (Fig. 5.1). The application of improved modern cultivars developed through breeding or genetic engineering supported by the provisioning of irrigation, especially in the form of groundwater (Fig. 5.2), easier access to fertilizers (Fig. 5.3), assured market, cheap labor, etc. catalyzed the gradual process of rising productivity. And, the enhanced productivity culminated in a huge rise in production (Fig. 5.4).

So, can we find a causal link between crop improvement programs and dwindling agrobiodiversity? Can we trace back the huge rise in productivity to a limited number of modern cultivars? And does that not translate to the process of abandonment of heirloom seeds or landraces and eventually to genetic diversity erosion? The response is likely to be positive; we can find a set of probable drivers at large. The massive improvement programs, mediated through the influence of science and technological advancement and application undertaken over a large spatiotemporal scale, led to an intensified production. Dabbling with and accelerating the yield factor has been the prime mover in addition to other crucial objectives. So, the steady intensification of production happened over the period of sixty to seventy years mostly driven by the yield increment. It also seemed to be reliant on a few sets of elements in a package, i.e., improved seeds, enhanced fertilizer or pesticide applications, elevated use of groundwater, extension support, etc. that were intricately linked and underlying drivers of agrobiodiversity depletion.

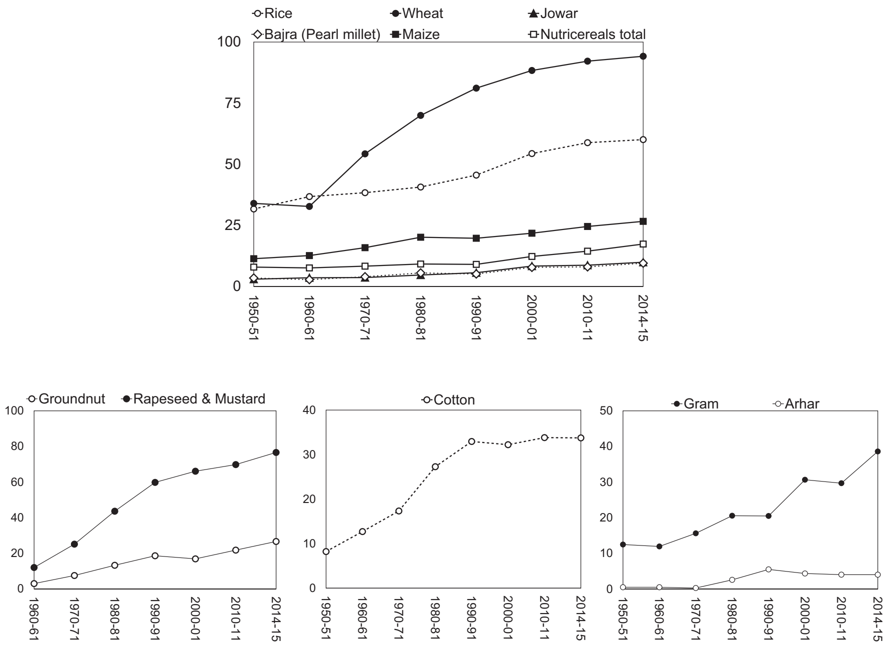

Fig. 5.2 The increment in acreage under irrigation facility (as a percentage of total acreage) of major food and fibre crops in the last sixty-seventy years period [Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India]

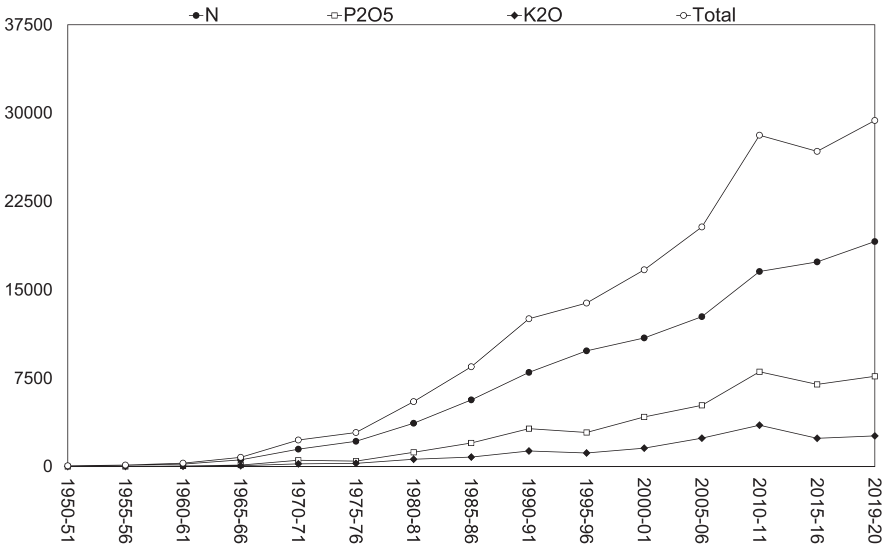

Fig. 5.3 The increment in total fertilizer consumption (Nitrogen (N), Phosphorous (P), and Potassium (K), and total NPK) (in thousand tonnes) in the last sixty-seventy years period [Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India]

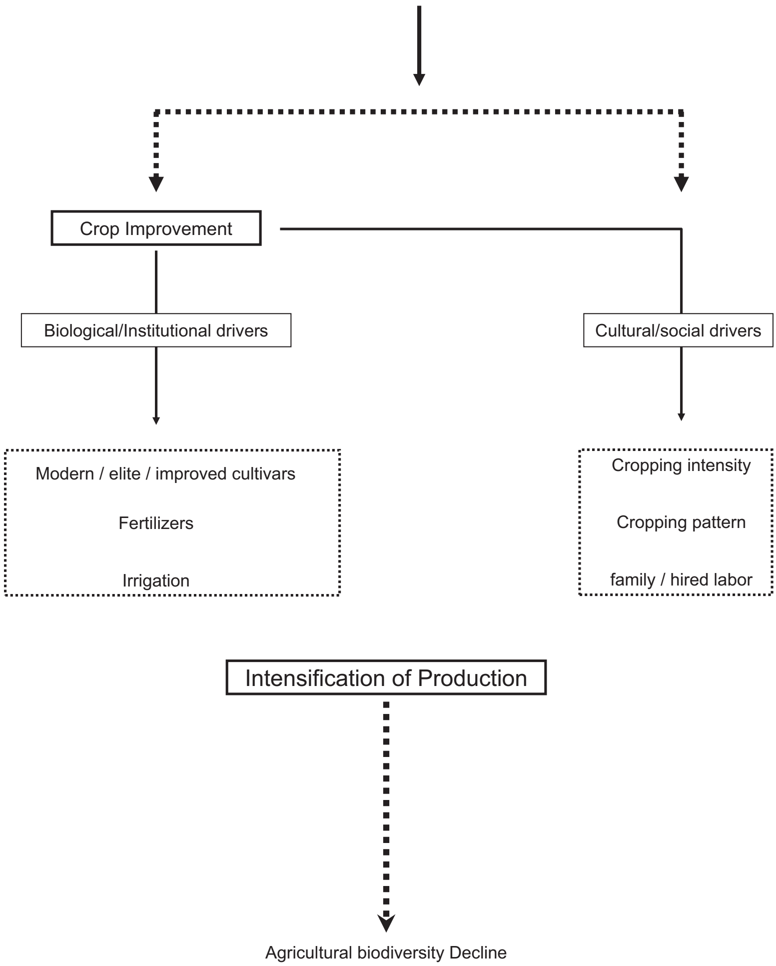

Fig. 5.4 The network of underlying drivers of agrobiodiversity decline

5.6 Implications for Food Security

Science and technological progress have ushered great hope in raising productivity, containing few diseases or pests, customizing crops for specific qualities, enhancing abiotic stress tolerance, or shortening maturation time to enhance production. Seemingly, it allowed farmers to reap a better harvest and the country to reach a state of food security. However, among several well-documented fallouts, the spatio-temporal decline of agricultural biodiversity and its impact on various social, economic, and cultural fronts has been quite evident. Here, I summarize the key effects of the decline of diversity that underlie the larger development program.

5.6.1 Disease /Pest Susceptibility

The decline in agricultural biodiversity can be gauged as follows: of approximately 250,000 plant species about 50,000 are edible. We actually consume no more than 250, out of which fifteen crops give 90% of the calories in the human diet, and three of them, namely wheat, rice and maize provide 60%. In these three crops, modern plant breeding has been particularly successful, and the process towards genetic uniformity has been rapid – the most widely grown varieties of these three crops are closely related and are more or less genetically uniform (pure lines in wheat and rice and hybrids in maize). The major consequence is that our main sources of food are more genetically vulnerable than ever before, i.e. food security is potentially in danger (Ceccarelli 2009).

The major biological effect of crop improvement is the reduction of diversity, phenotypic and genetic (Fu 2006, 2015; Louwaars 2018) which has a long-standing effect on the adaptive evolution of the organisms. In the distant past, crop plants founded by small population(s) have undergone genetic bottleneck(s) while domestication, either single or multiple times in geographically disjunct locations (Doebley et al. 2006). While it has caused a drastic reduction of diversity from their wild ancestors due to the bottleneck, ancient farmers were able to unleash and tap diversity through artificial selection of favored mutation, curation, maintenance, and enhancement; and it occurred over large geographic regions over several thousand years that facilitated modern crop species to accumulate genetic and phenotypic diversity (Hufford et al. 2019). Geneflow from wild ancestors or semi-domesticates, hybridization and random mutation are used to operate in unison to create this pool (Cornille et al. 2014; Meyer and Purugganan 2013). The outcome was enormous diversity of domesticated, semi-domesticated, and naturalized edible species manifested in thousands of local landraces (Dwivedi et al. 2016; Ray et al. 2013). However, the modern-day improvement phase was another such bottleneck that crop plants encountered and it has also resulted in the decline of diversity since even a smaller subset of selected individuals was chosen for further experimentation (Van de Wouw et al. 2010a, b). Also, plant breeding technology attempted to combine as many 'favorable traits' as possible in one genotype or maximize the presence of such traits in one population. Therefore, diversity in the variety or within populations is further reduced. Moreover, it preferred pure-line selection instead of multiline as in landraces or traditional varieties. The net effect is nurturing uniformity in the field (Louwaars 2018; Fu 2006, 2015).

So, the reduced diversity in crop plants compared to their wild ancestors is common, but the magnitude of the diversity loss in plant breeding or improvement programs is alarming in terms of sustaining agriculture, combating disease or pests, adapting to climate change, mitigating crop loss, and ensuring food security (Fu 2006, 2015, 2017). As discussed in the last few sections, the reduction of diversity is sometimes so acute that only a few desired cultivars dominate agricultural fields. The effect of narrowing of diversity is quite severe in evolutionary terms, it robs the organism of the power to adapt to any change in its environment, be it a change in climate, a disease, or pest outbreaks (Edwards 1996). There are many examples from the past or relatively recent times when a narrow genetic diversity of crop plants in monocultures caused disease emergence or recurrence, crop loss, or famine in extreme cases (Thrupp 2000, 2003; Pring and Lonsdale 1989). On many occasions, it could be difficult to identify the actual causation of such events, as many players loom large and co-contribute to the disease outbreak, e.g., the repeated infestation of cotton plants by cotton bollworms, the emergence of resistant bollworms can be cited to substantiate the claim that low genetic diversity could be one of the factors along with many other socio-economic or cultural variables. Sometimes, secondary or minor pests reincarnate into major pests owing to a change in the microenvironment and susceptibility of the improved ones, e.g., brown plant hopper in high-yielding rice cultivars (Ray 2022). Taken together, it hints at greater risk and vulnerability to various biotic and abiotic stresses, let alone climate change.

5.6.2 Gradual and Inevitable Changes in Food and Nutrition

The causal link between crop improvement and its detrimental effect on food and nutrition is not generally spoken aloud but the reverse is mostly cited as the benefactors. The modern cultivars are often portrayed as a silver bullet to fight hunger and malnutrition through the overtly simple narrative of customized genetic manipulation, overproduction, and lowered food prices (Bouis and Saltzman 2017; Khush 2001). However, when analyzed closely a distant but clear link can be perceived, at least in selected cases. The context and the causal factors are somewhat comparable to the intermediate or inclusive factors that have been proposed to study the links between malnutrition and crop improvement by Ferguson et al. (1990).

I briefly argue on this aspect drawing on two main staples, rice and wheat. It has been observed that the overwhelming diffusion and acceptance of modern high-yielding cultivars of rice and wheat has cascading effects on various fronts pertaining to food and nutrition through the complex and interrelated chain of factors. Although it operated distantly and indirectly through various pathways involving a number of intermediate factors it finally resulted in food or nutrition insecurity. Divergent agrarian activities and associated cultural practices have been molded and reshaped by the production of high-yielding varieties of rice and wheat. For example, through monocropping, changed cropping patterns, high-input demanding systems, overproduction of staples, and subsequent feeding of the same product to the public distribution system, the rice-wheat cropping systems employing HYVs eventually modified the food systems of many regions of the country (Ray et al. 2021) (Fig. 5.5). Increased acreage of rice and wheat acted in some ways to discourage the cultivation of pulses, fruits and vegetables, and coarse cereals. The staples were further channelized into social welfare programs like public distribution systems that essentially relied on mostly rice and wheat which made their access easier in various parts of the country. All of these, cumulatively, tend to have an impact on the food and nutritional outcome of a large section of society (Singh 2000; Kataki 2002).

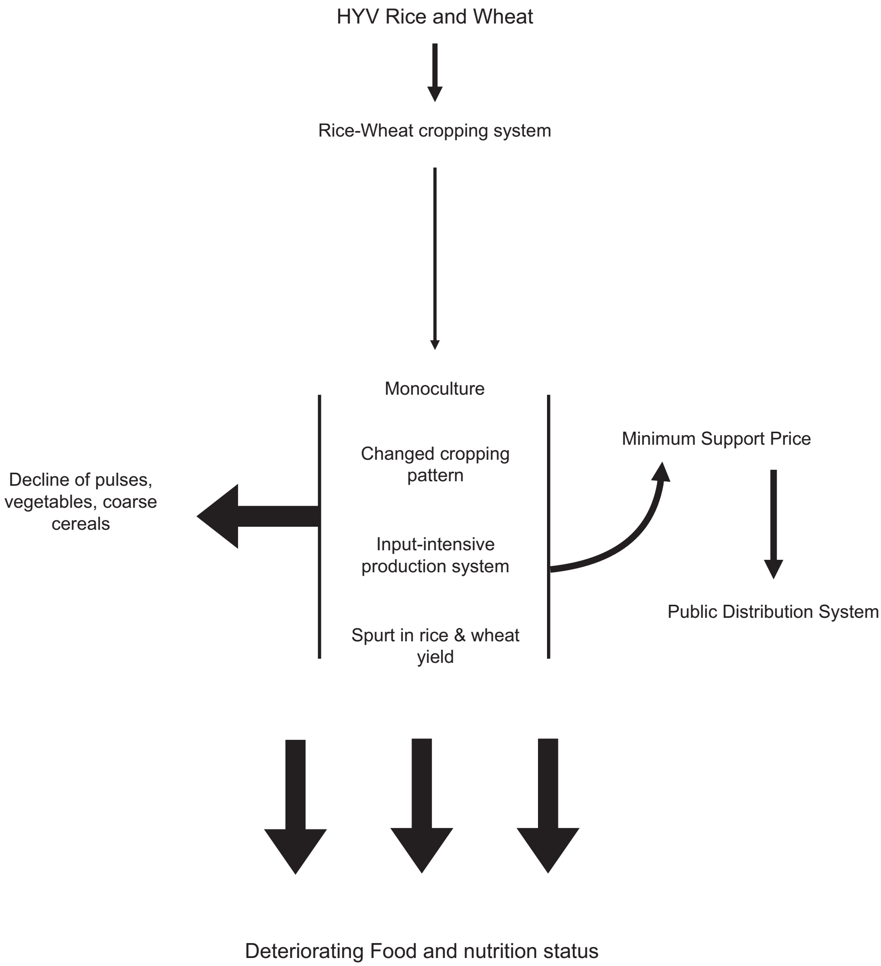

Fig. 5.5 A probable causal link between crop improvement and decline of food and nutritional security through various interacting factors

5.6.3 Seed Politics and Growing Corporate Power in Agriculture

Plant breeding technologies developing newer cultivars have permeated almost every corner of the country and are embraced largely by farmers. Be it high-yielding or hybrid seeds, or seeds with specific traits to fend off insect pests or grow in diverse agroecological systems, the Indian seed sector has become increasingly dominated by modern or improved seeds, where traditional seeds or farmers' varieties are faintly-represented (Chauhan et al. 2016b; Chauhan et al. 2017; Nagarajan et al. 2006). In other words, heirloom seeds, the regenerating propagule, have long vanished from the farmers' hands with few exceptions and so the imminent functions of seed banks or networks have been grossly disrupted. Though informal seed networks, local or small-scale seed traders fostering traditional or local seed remain instrumental in places they are exceptions rather than rules. Rural markets, village *haats* or local *shandies* (regular or weekly open-air markets), village fairs or *melas*, a cauldron of cultural diversity encouraging seed exchange, turned almost non-functional or operative in distant geographies away from industrial agricultural foci and their surroundings, or their purpose has been changed. The loss is spatially heterogeneous, some of the crops under improvement programs or direct market linkage are more affected than others (Chauhan et al. 2016b; Schöley and Padmanabhan 2017; Nagarajan et al. 2007).

Following the trails of plant breeding, the rapidly advancing domain of biotechnology and its under- or unregulated application sparked the proliferation of corporate power in agriculture and food system (Clapp 2018; Flachs 2020; Hendrickson et al. 2017; Howard 2009, 2015; Shiva and Crompton 1998). The ripples of the global agrarian change have affected the Indian seed sector which gradually became dominated by proprietary seeds developed and sold by private companies although public-funded seeds produced by the Govt. institutes still held a stake (Chauhan et al. 2016a, b; Nagarajan et al. 2007). The seed industry of India has grown enormously over the past four decades where both private and public sectors were actively involved in seed production, high-yielding varieties of wheat and rice, the hybrids of maize, millets, and various vegetables. It was supported by sound policy measures provided through the establishment of public sector organizations (Singh et al. 2019). Not as fiercely as cotton, high-yielding or hybrid seeds or seeds with disease resistance gained acceptance all over. The private sector has also started to play an important role in the supply of quality seeds of vegetables and crops, planting materials of horticultural crops, like tomato, brinjal, chilies, gourd, okra, sorghum, bajra, castor, sunflower, watermelon, etc. (Tables 5.1a, 5.1b and 5.1c).

The case of some low volume high value crops, e.g., cotton, reflects an extreme side of seed monopolization and consolidated corporate power (Murugkar et al. 2007). Post-independence, the acreage of the native species of cotton has already shrunk greatly. Cotton fields have been primarily populated by varieties and hybrids of *G. hirsutum* grown in input-intensive monocultures (Boopathi and Hoffmann 2016). After the approval and commercial cultivation of genetically modified cotton or Bt cotton hybrids, in 2002, the situation became even more critical (Gutierrez et al. 2015; Gutierrez 2018). It brought in the consolidated corporate power on seeds with the monopolization of bt seed technology initially by the Global seed giant Monsanto; afterward, a few companies stepped in to sell the bt seeds (Ramaswami et al. 2012). It was adopted like wildfire for its 'proclaimed' high productivity and has been grown in almost 90% of the Indian cotton fields, yet the claim of higher yield is deeply flawed (Kranthi and Stone 2020). Additionally, the collateral damage of Bt cotton was enormous (Stone 2011; Glover 2010). The 'success story' of higher production sparked a series of consequences at the socio-economy and ecology frontiers, i.e., an exponential rise in the use of pesticides and other agrochemicals, the emergence of new resistant pests and pathogens, burgeoning farmers' debts,

Table 5.1a The number of hybrids in major field crops developed by the private and public sector in India

Crop	Till 2001–02		2002–03 to 2009–10		Total		
	Private sector	Public sector	Private sector	Public sector	Private sector	Public sector	Share of private sector hybrid in total hybrid
Cotton	150	15	43	10	193	25	88.5
Maize	67	3	36	25	103	28	78.6
Paddy	12	4	11	5	23	19	54.8
Wheat	X	X	3	0	3	0	100
Pearl millet	60	6	22	7	82	13	86.3
Sorghum	41	5	12	8	53	13	80.3
Pigeon pea	X	X	1	2	1	2	33.3
Soybean	X	X	2	X	2	0	100
Sunflower	35	6	13	10	48	16	75
Jute	X	X	X	23	0	23	0
Mesta	X	X	X	11	0	11	0
Castor	X	X	4	9	4	9	30.8
Green gram	X	X	1	X	1	0	100
Mustard	X	X	11	1	11	1	91.7

Source: Singh and Chand (2011); Singh et al. (2019); Seeds Division, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, NSAI (2005)

Table 5.1b A few vegetable hybrids developed by the private and public sector in India (1998–2005)

Crop	Public sector	Private sector
Tomato	3	160
Brinjal	8	218
Chilli	2	73
Capsicum	1	31
Cauliflower	1	35
Cabbage	0	20
Okra	2	32
Watermelon	2	25
Cucumber	2	10
Gourds	6	80

Source: Singh and Chand (2011); Singh et al. (2019); Seeds Division, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, NSAI (2005)

Table 5.1c A comparison of total seed production by the public and private sectors

Year of production	Total seed production (MT)	Seed produced by public sector (MT)	Seed produced by private sector (MT)	Share of private sector (%)
2003–04	1.32	0.7	0.63	47.48
2004–05	1.41	0.77	0.63	45.02
2005–06	1.48	0.79	0.69	46.8
2006–07	1.94	1.15	0.8	41
2007–08	1.94	1.12	0.83	42.59
2008–09	2.5	1.51	1.0	39.78
2009–10	2.8	1.71	1.09	38.93
2010–11	3.22	1.66	1.56	48.45
2011–12	3.54	1.81	1.73	48.87
2012–13	3.29	1.61	1.67	50.76
2013–14	3.47	1.68	1.79	51.59
2014–15	3.52	1.51	2.06	58.52

Source: Singh and Chand (2011); Singh et al. (2019); Seeds Division, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, NSAI (2005)

distress, and suicides (Nagrare et al. 2009; Stone 2011). It appeared that the cotton farmers are held in never-ending spirals of debts and misfortunes.

Despite the overarching problem of the corporatization of food systems and flourishing seed sectors, informal seed systems have been functional or resurrected to different degrees at disparate geographic locations through the initiatives by village communities with the interventions of local NGOs or individual seed savers' initiatives. They play a key role in thriving community seed banks, documentation of agrobiodiversity, conservation, and utilization of heirloom seeds noting their individual properties. In opposite to proprietary seeds or industrial agriculture, they can be a good hope for climate-resilient agriculture.

5.6.4 Loss of Cultural Diversity of Food

The loss of myriad landraces of many crops tends to have serious repercussions on the cultural diversity of food. Since food is not merely the biological product grown in the field in the form of cereals, pulses, oilseeds, fruits, vegetables, and spices; it is also imbued with rich biological and cultural diversity that is closely interwoven into how we accept, consume, and enjoy our food. These attributes epitomize its cultural underpinnings. In other words, it implies how the biological components are processed or cooked, i.e., the numerous means to prepare them to suit our own meals that we relish. Therefore, food is not only a biological product that allows us to derive energy and nutrition, it embodies our cultural identity. In this realm, the loss of traditional varieties or landraces has a long-standing effect on our food culture. On a similar note, the loss of taste or related cultural attributes are also closely entwined with the food. Quite related to the notion, the significance of cultural aspects of traditional varieties has been emphasized by several researchers (Bellon 2004; Galluzzi et al. 2010; Rana et al. 2007). A review by Ficiciyan et al. (2018) underscored the choice of landraces by peasants not only due to their adaptive ability or stable yield or disease resistance but also for their cooking properties. We come across similar observations by Brush (2004) on selected potato landraces that are grown for their special culinary properties. Extinction of landraces, hence, is intricately associated with the loss of culture in the form of abandonment of certain delicacies, special cuisines, feast or ritual food, feel-good food, etc. In a recent article, Deb (2021) commented that we tend to lose our cultural diversity with the loss or extinction of rice landraces. These landraces not only encapsulate a body of folk knowledge pertaining to the distinguishing properties but also embody local food cultures and ensure food insecurity for poor and marginal farmers. Citing the example of the Philippines where a special fabric has disappeared with the extinction of the rice variety yielding the fiber, he continued that many of the delicacies have vanished with the disappearance of special rice varieties throughout Bengal. Perhaps Bengal is just one such example, the heat of agrarian change owing to newer improved, modern or elite varieties has percolated geographically and into all spheres of our life. However, the diminishing spectra of biocultural diversity with the overarching presence of modern or improved cultivars remain largely undocumented or under-researched.

5.7 Conclusion

The rapid and ubiquitous decline of agrobiodiversity has become an intense global crisis. However, the magnitude and spatial scale of the decline of selected crops have received more attention than the causal processes, therefore, linearizing the complexity of the problem that falls short of understanding the multiple actors at work and the identification of the underlying drivers. I have argued, in this article, that the change can be better viewed and deciphered through the larger political ecological lens embedded in the historical development of crop breeding and improvement leading to the global agrarian change. Though kickstarted later in India, the crop improvement programs gained impetus from the Green Revolution and garnered its ever-increasing power to mold agrarian activities. In light of that, I have struggled to outline the macro-level scientific, technological, and socio-political development that affected crop diversity through a complex web of interactions (Fig. 5.6).

In a nutshell, the analyses have broadly demonstrated the nuances of homogenization of agricultural diversity owing to the mass adoption of improved cultivars. It has portrayed how gradual progress in breeding and development of new cultivars created the necessary podium for technology transfer and adoption, how the modern cultivars swept into the field, led to the large-scale acceptance of a few, and finally ended up encompassing a major fraction of acreage. All of it happened at the cost of

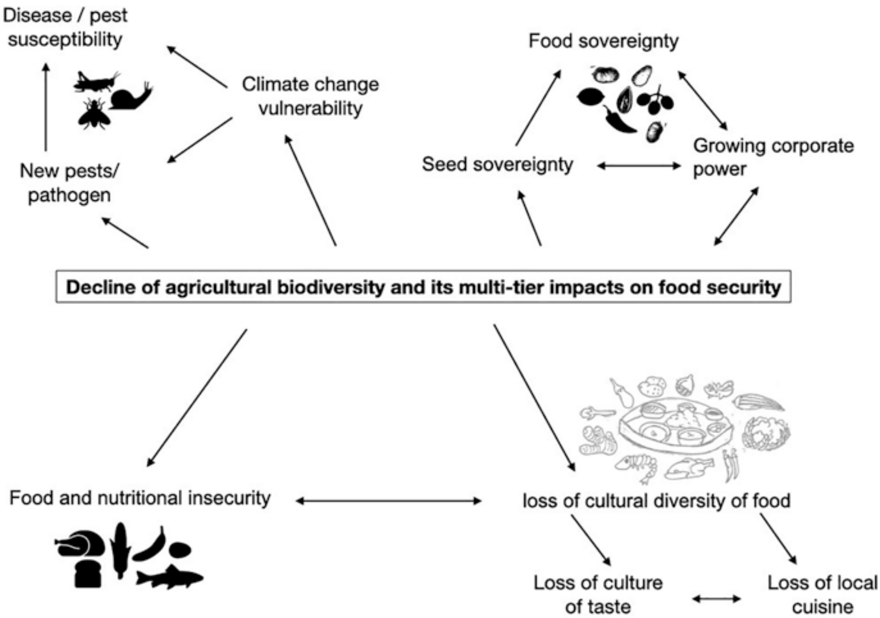

Fig. 5.6 The decline of agricultural biodiversity and its multi-tier impacts on food security through a complex web of interactions

traditional varieties or landraces used to populate the cultivation field. For many crop species (e.g., rice, wheat, potato), just a few improved cultivars held a significant percentage of acreage that resulted in severe homogenization. Although an introduction and wider adoption were largely pioneered by the Green Revolution cereals, rice and wheat, the general trend of the decline and dominance of a few cultivars have been pervasive across crops. The recent invasion of biofortified and GM crops opens up newer avenues of further decline that has been effectively portrayed by the Bt cotton. Looking closely, the productivity or yield increase seems to be the prime mover behind the improvement programs. Of various effects, I have delineated the implication of the decline in food security. On the biological ground, it emphasized the impending threats on a nearly genetically uniform pool of crops from various diseases or pests that may endanger global agriculture. On the socioeconomic side, it allowed us to gain a nuanced understanding of the growing corporate power in agriculture. My analysis also recognizes the impacts on the changes in food and nutrition, and the loss of cultural diversity of food which remain an underappreciated realms of food security policies.

In the end, the fundamental question remains whether we have any solution(s) to avert this loss. The reversal of the process of decline or slowing down is not quite an easy task with the promotion of a small suite of improved cultivars instrumental in the background. The development of newer and 'superior' cultivars by inserting novel gene(s) or fragments from the landraces or wild relatives works in tandem; it narrowly considers a few gene variations and undermines the allelic diversity within the landraces. For example, a single 'super' cultivar (e.g., Green super rice), a purported panacea to the global hunger problem, could further homogenize the rice gene pool and should be avoided. Rather it would count on managing diversity in a holistic agroecological framework to lessen external input usage, adhere to recycling, diversify crop package, and build resilience towards climate adaptation; merely zeroing in on the problem and emphasizing it in isolation would not be productive. The steps could hinge on nurturing conservation, utilization and management of diversity, and the activities that foster the use and exchange deserve to be adopted and disseminated. I highlight a number of related measures to enhance the use of biodiversity and associated knowledge. However, it could be fruitless unless the programs that facilitate the erosion of diversity, such as those described at length previously, are simultaneously curbed. This requires a paradigm shift, a gradual reorientation of the socio-economic and institutional arrangements that support such practices.

1. A complementary approach to embrace *ex situ* and *in situ* conservation: While a lot has been spoken about the efficiency of *ex situ* approaches and the fund has been channelized to set up genebanks, *in situ* received step-motherish treatment. *In situ* enterprises like community seed banks or seed savers' initiatives should also be bolstered and the message should be disseminated to encourage such social movements. Empowerment of local institutions like community seed banks can be pushed to operate in a decentralized manner at the level of blocks or village-clusters serving the demand of local or regional crops and thereby harnessing the potential of heirloom seeds. It could be done at a much wider scale, local and regional levels, meeting local seed needs, engaging communities, and through the cooperations with regional agricultural stations like Krishi Vigyan Kendras (KVKs) (Fig. 5.7).
2. The premise of community seed banks brings in the necessity of heirloom seeds or landraces that are capable of growing in diverse agroecological conditions. They can offer stable and moderate yield even under not-so-favorable conditions in contrary to resource-hungry high-yielding cultivars. They retain the power to withstand climatic vagaries, or other biotic or abiotic stresses more effectively than the improved cultivars thereby insulating them from risks and instilling resilience in farming practices. The promotion and advertisement of the capacity and benefits of the traditional, heirloom, or *desi* seeds along with the extension services (like integration in natural farming or regenerative agricultural practices) deserve to be recognized in the Govt. policies.
3. Close links with the local or hyper-local markets and supply chains are to be established, they can essentially support smallholders and marginal farmers to sell their produce and encourage them in using regional agrobiodiversity. In many places, they are functional in different local avatars, e.g., village *haats* or local *shandies* (regular or weekly open-air markets), village fairs, *santes,* or *melas* are melting pots of biological and cultural diversity. They tend to encourage the sale of local agricultural produce (cereals, vegetables, etc) many of

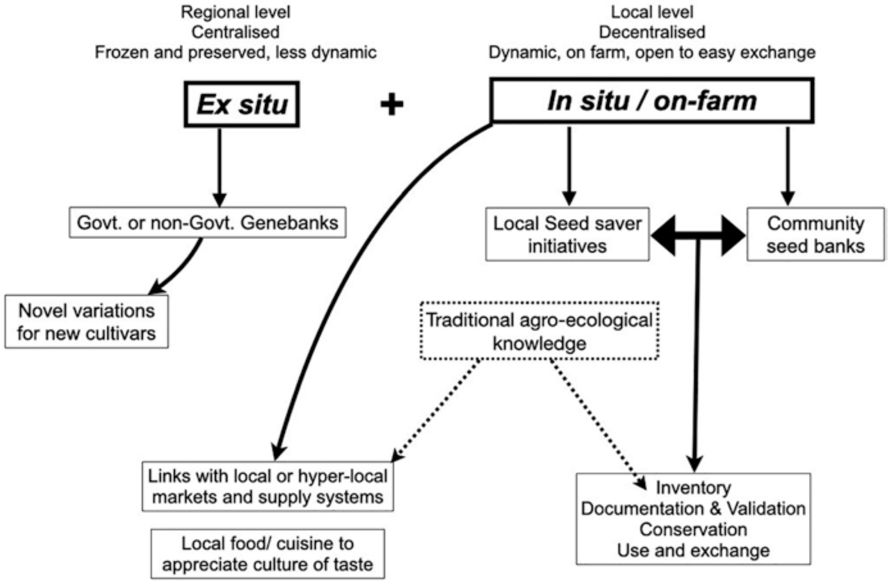

Fig. 5.7 A complementary approach to conservation and utilization of agricultural biodiversity

which could be local varieties or landraces, exchange of heirloom seeds in small to moderate quantities, and facilitate small-scale farmer producers who used to sell their excess produce. It has to be resurrected, promoted, and the message requires to be disseminated in opposition to the mass formal procurement systems (by offering minimum support price or MSP) which does not take diversity, nutritive, or cultural qualities of crops into account.

4. Invigorating traditional agroecological knowledge that is closely attached to agriculture. Transforming the notion of farmers as passive takers but accepting them as partners in agricultural endeavors is essential. They are to actively be associated with the various courses of action, like choosing varieties, participatory plant breeding, field management, resource recycling, disease containment, etc. Their central role as innovators and resolvers in local problem(s) has to be recognized and appreciated. It opens up avenues for social-innovation-driven solutions to local or region-specific problems or bottlenecks. Where a bottom-up approach could be more yielding and sustainable than the bureaucratic formulation.

In essence, agricultural biodiversity can not be conserved just as the relicts of the past or as the frozen heritage of humankind. Its survival can only be sustained through recurrent and decentralized utilization and management as well as through an appreciation of local food culture. To nurture the use of agrobiodiversity, encouraging informal cultivation or moderate management in homesteads, fringes, pastures, or fallow lands, engaging local communities, outreach, and awareness generation are essential. Besides, they can be integrated into different government interventions like nutrition gardens or kitchen gardens for small-scale cultivation and easy access. On a regional scale, '*Poshan Abhiyaan',* or the scheme for holistic nourishment under the National Nutrition Mission of the Government of India to improve nutritional outcomes of children, pregnant women, and lactating mothers can be integrated. The Ministry of Human Resource Development's 'School Nutrition Gardens' program could be another way to sensitize younger people and encourage them to grow and consume a diversity of plants as part of the schools' mid-day meals (Ray and Ray 2023). On the other hand, local culture of taste can be advertised and rekindled through ecotourism or rural tourism where people can relish 'exotic' cuisines prepared from local edible biodiversity. It could facilitate the creation of a dynamic link between consumers and producers.

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Chapter 6
Aquaculture: Contributions to Global Food Security

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6.1 Introduction

After the Second World War (1939–1945), issues related to food security become more apparent. Some scholars connect this to the beginning of investigations into demographic food and nutrition security (Akbari et al. 2022). One of the most significant challenges for populations and environment was managing the increased consumption of food (Jambo et al. 2021). Problems with global food security are primarily caused by an expanding world population, unanticipated climate change, and limited natural resources to support food production (Kidane and Kejela 2021). There is a common apprehension that the demand for food will outstrip the available supply and it may lead to poverty due to scarcity of food, low economic output, insufficient food distribution, and unhealthy food intake habits (Anghinoni et al. 2021). With a projected 9.7 billion population by 2050, a 25 to 70% increase in food will be required which is a significant challenge for the availability of high-quality and nutrient-rich food (United Nations 2019). Additionally, factors such as deprivation, natural calamities, political violence, and geographical factors contribute to worldwide food insecurity (Nabuumaet et al. 2021). Despite a declining of natural resources and conflicting demands for input consumables with an agricultural sector, food security remains a steadfast concern. The emergence of the middle and upper classes is accompanied by population growth and is characterized by increased wages (in China and Southeast Asia) and a shift towards meat and seafood-based

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diets, has put pressure on the animal food industry to increase production to meet demand (Benton et al. 2018). However, this has resulted serious issues such as overgrazing, resource depletion, and ecological imbalance (Rivera-Ferre et al. 2016).

The production of aquatic animals or aquaculture contributes a significant percentage of animal-derived proteins. In 2017, fish accounted for approximately 17% of total animal derived protein, and 7% of all proteins consumed globally (https://www.fao.org/state-of-fisheries-aquaculture/2020/en). In many low income and food deficient countries (LIFDCs) fish contribute more than one0third of the total animal protein (Béné et al. 2015). Fish are important source of not only protein but also long chain polyunsaturated fatty acids (LC-PUFA) and essential micronutrients such as vitamin A, D, B and minerals like calcium, phosphorus, iodine, zinc, iron and selenium (Béné et al. 2015, Tilami and Samples 2018). A recent review on the nutritional value of molluscs, especially edible snails, indicated their excellent quality, particularly with respect to their protein and mineral content (Baghele et al. 2022). Aquaculture has been the fastest-growing food production sector over the past three decades, with annualized growth rates of 10% in the 1990s and 5.8% from 2000 to 2016 (FAO 2018). There are two types of aquaculture output: "unfed" and "fed." Unfed aquaculture depends on animals like silver carp and grass carp receiving food from the habitat (Tacon and Metian 2015). Excluding seaweeds, fed aquaculture is the largest and fastest-growing sector of the industry and frequently involves feeding animals with readymade aquafeeds or processed fish. In the past, forage fish and small pelagic fish were caught and used for the mass production of fish products (primarily fish meal) and fish oil used to feed animals. The production rate of wild fisheries peaked in 1995, followed by a steady decline. At the same time, global fish consumption is growing at an annual pace of 1.5% per capita. Unfortunately, the rapid expansion of aquaculture has put a tremendous burden on the feed sectors of aquatic resources. Since approximately 10% of fish biomass harvested in wild-capture fisheries is used to feed valuable, often carnivorous species, concerns have been raised about the sustainability of the supply of this natural resource (FAO 2018).

However, estimates for household consumption of fisheries and aquaculture in 2011 ranged from 85 to 89% among the top ten aquaculture-producing countries (representing 87% of global aquaculture production, 51% of the total population, and 52% of the undernourished population), emphasizing the importance of aquaculture (unfed and fed) for the supply of human consuming protein (Belton et al. 2018). Future aquaculture industry advancement is therefore crucial for long-term health and nutrition (Tran et al. 2017).

In 2016, 4.5 million tonnes of fish meal and 0.9 million tonnes of fish oil were produced, respectively, of which 69% and 75% were used in aqua feeds. Additionally, 23% and 5% of this fish meal is used in the diets of pigs and fowl (Auchterlonie 2018). Moreover, the aquafeed yield for all aquaculture species is expected to rise by 75% between 2015 and 2025, from 49.7 million tonnes to 87.1 million tonnes. The current feed formulas indicate that the amount of wild-caught forage fish necessary for this growth of aquaculture is not feasible, and the future availability of this resource is a cause for serious concern. To provide a higher proportion of nutritious seafood to the growing population, the inclusion levels of sustainably harvested small pelagics for fish meal and oil in aquafeed requires to be reduced at faster rate. Animal byproducts such as meat and bone meal, chicken meal, edible insects are alternative protein sources to fish meal in aquaculture feeds. However, plant-based proteins like soy concentrate have significant limitations, including the presence of anti-nutritional elements. Furthermore, the industry's capacity to expand is restricted without imposing an additional burden on land, water, and nutrient resources (Malcorps et al. 2019).

6.2 Current Global Status of Aquaculture and Fisheries

6.2.1 Global Fish Production

Comapred to 2019, the production of aquatic animals has gone up by 0.2%, but it has decreased by 0.6% when compared to the previous record production in 2018, as reported by FAO in 2020 (FAO 2020). However, the overall production in 2020 was quite similar to the average yearly production between 1995 and 2020 (Figs. 6.1 and 6.2), indicating that the capture fisheries remain stable, as stated in the FAO report. Even though the growth rate has slowed down in recent years, the aquaculture industry has sustained its upward trend over the previous 2 years. In 2020, the second-highest amount ever recorded was 157 million tonnes of aquatic creatures cultured for direct human consumption.

The decline in capturing fisheries in 2019 was significant, down by 4.4% from 2018, which was further worsened in 2020 by another 2% presumably due to the aftermath of the COVID-19 pandemic and associated factors. The COVID-19 disease outbreak interrupting fishing activities, the ongoing decline in China's catches

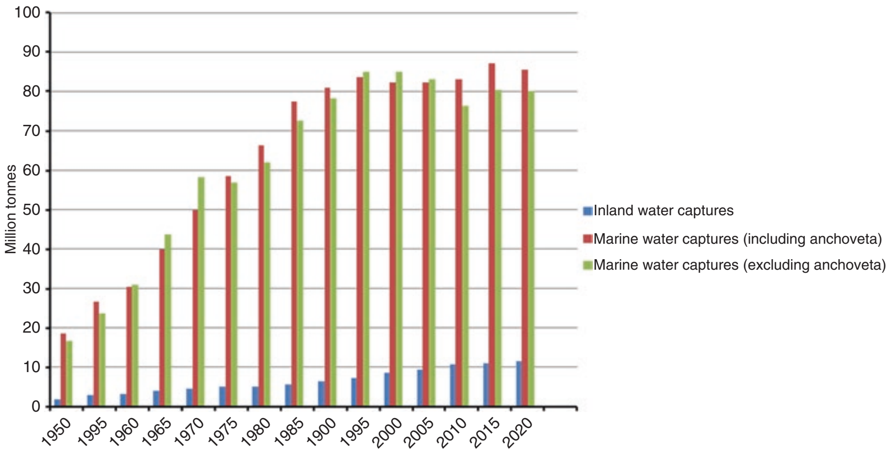

Fig. 6.1 Worldwide inland and marine aquaculture trends. (FAO 2022)

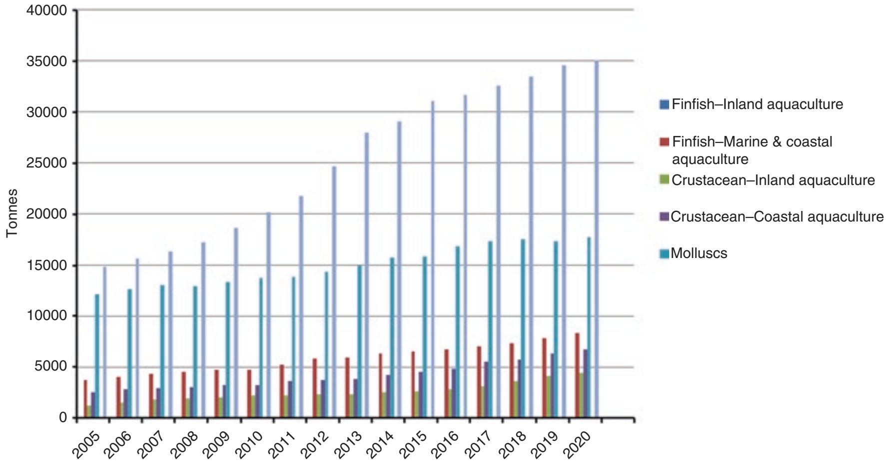

Fig. 6.2 Worldwide aquaculture production from different subsections during 2005 to 2020. (Source: FAO 2022)

(10% lower in 2020 compared to the average of the previous 3 years), and a decrease in naturally varying anchoveta catches are all likely factors that contribute to the lowering in global capture fisheries production in 2020, which was 90.3 million tonnes, a drop of 4.0% from the average over the previous 3 years (FAO 2020).

These producers made up over 49% of the world's total capture output in 2020, including China, Indonesia, Peru, India, the Russian Federation, the United States of America, and Vietnam (FAO 2020). FAO reports that despite the COVID-19 pandemic's global spread, the aquaculture sector has continued to flourish in the year 2020. Aquatic animals weighing 87.5 million tonnes were produced for human consumption, about 35,000 tonnes of seaweed and other algae used for food and non-food purposes, and 700 tonnes of shell and pearl jewelry.

At the regional level, in 2020 African aquaculture's annual production, excluding algae, decreased by 1.2% compared to 2019. The primary cause for decline was the drop in output in Egypt, Africa's top producer. Additionally, Nigeria, the largest producer in sub-Saharan Africa, experienced a further decrease in output, falling by 9.6%. Nervertheless, rest of Africa saw a growth of 14.5%, with aquaculture production from 346,400 tonnes in 2019 to 396,700 tonnes in 2020, a 14.5% rise. On the other hand the largest producers in the Americas, Asia, and Europe—Chile, China, and Norway—all had an increase in output in 2020, compensating for the decline in some countries in their respective regions (FAO 2020). It is also worth mentioning that overfishing might have significant detrimental effects on ecosystems and resources, reducing the production of essential foods sources and leading to adverse social and economic consequences.

6.2.2 Livelihood in Fisheries and Aquaculture

According to FAO (2022) estimates, the primary fisheries and aquaculture sector provided employment to around 58.5 million people in 2020 (FAO 2022). Among those directly employed, women accounted for approximately 21%, with nearly 50% working full-time across the aquatic value chain, including post-harvest operations. After taking dependents into account, it is estimated that around 600 million people rely on the fisheries and aquaculture industries for their livelihoods. However, the COVID-19 pandemic has had a widespread impact on employment across the fisheries and aquaculture value chain (Chan et al. 2021).

To promote equitable and sustainable growth, as well as gender equality, the "Blue Transformation" program has been introduced with the aim of enhancing or boost the contribution of aquatic food systems to feed the expanding global population (Krause et al. 2022). To ensure the achievement of the Sustainable Development Goals and maximize the contribution of aquatic food systems to food security, nutrition, and accessible healthy diets, Blue Transformations is expected to play crucial roles.

Blue Transformation's three key goals are as follows:

1. Intensive and widespread aquaculture that is sustainable: To keep up with the increasing demand for aquatic foods and ensure sustainability, responsible development of aquaculture is essential over the next decade. This will require effective governance structures, technical innovations, investment opportunities, and advancement in value chain advances (Giri et al. 2022). Taking into account the national and regional contexts, the goal is to increase global aquaculture production by 35–40% by 2030 (FAO 2020).
2. Proper administration of all fisheries: FAO and its partners must implement and disseminate efficient ecosystem-based fisheries management methods that rebuild exploited resources while restoring ecosystems to healthy, productive conditions. The goal is to maintain fish populations at levels that offer their highest sustainable yield by ensuring effectiveness of all fisheries and aquatic ecosystems. This would involve increasing global capacity for routinely gathering and analyzing data to assist decision-making, especially in areas with weak capability and little access to data (Sumby et al. 2021). Additionally, it would support fair livelihoods, improve social results, and guarantee small producers' access to resources and services.
3. Modernized food chains: Public and commercial actors, including consumers, may decrease waste and loss through improved value chains, improving traceability and transparency, easing trade, and providing access to profitable markets. Promoting good eating habits and incorporating aquatic foods in national food security and nutrition policies are also crucial, necessitating actions to raise consumer knowledge and expand access to nutritious, safe, and healthy aquatic foods for everyone (Brouwer et al. 2021).

6.2.3 Shellfish Production as a Possible Future Food

The FAO lists 73 significant aquaculture species and their "Species Fact Sheet Information," which describes how to produce them and numerous cultural features. Moreover, half of the fish species on the FAO list are shellfish species, making up 52.2% of all fish species (Azra et al. 2021). This highlights the value of shellfish as a possible source of future food production for the entire world that comes from the saltwater ecosystem. Among these are the giant tiger prawn *Penaeus monodon*, the white leg shrimp *Litopenaeus vannamei*, the red swamp crawfish *Procambarus clarkii,* the Chinese mitten crab *Eriocheir sinensis,* and the mud crab *Scylla* sp. based on the most recent facts and values for aquaculture output (Tacon 2020). Projections of global aquaculture output have revealed that shellfish are one of the most profitable groupings for cultivation. FAO data on projected worldwide aquaculture production is used in this report's analysis of the growth of shellfish aquaculture (FAO 2020). When compared to other specific groups of finfish or aquatic plants, the shellfish groupings come out on top in terms of value, even though the data shows that finfish are the most popular aquatic species. Specifically, shellfish production has expanded ten-fold between 1985 and 2018, with a total production peaking at 27 MMT in 2018 as opposed to 2.76 in 1985. In order to be deemed suitable for future consumption, shellfish must satisfy five requirements. Three of these requirements are associated with the production phase (i) the ability to respond and tolerate to biotic and abiotic stresses, (ii) the availability of technical and biological knowledge, and (iii) the length of life cycle and brood stock maturation period); the remaining requirements pertain the consumption phase (iv. the nutritional value and health benefits of the shellfish, and v. the level of demand, cost, and affordability). According to FAO (2020), income generated from shellfish increased significantly from $3.56 billion in 1985 to $104.55 billion in 2018 (FAO 2020).

6.2.4 Tolerance of Biotic and Abiotic Stressors

Despite the changes in biotic and abiotic stresses brought about by climate change, shellfish may continue to be a sustainable food source as they are capable of mitigating their environmental impacts. According to a study by Gong et al. (2015), increased temperatures accelerate development and reduce intermolt intervals, while low temperatures may result in slower growth and longer intermolt period for certain shellfish, such as mud crabs, *Scylla paramamosain*. Azra et al. (2019) also observed that when raised at a high temperature of roughly 32 °C, the instars of the blue swimming crab, *Portunus pelagicus*, exhibited a shortened intermolt time and duration of exuviation. However, despite of climate resilience there are a few limitations and drawbacks to using marine shellfish species as the primary source of food (Azra et al. 2021). To address these challenges, it is important to focus on improving breeding techniques including genetic improvement, and enhancing environmental conditions during culture. Additionally, research is needed to develop improved survival and production traits for shellfish in the face of constantly changing biotic and abiotic stresses, which are necessary for maintaining or boosting production.

6.3 Aquaculture Needs Genetic Modification to Meet Future Demands for Animal Proteins

The most recent innovation in genetic engineering is gene editing. It is a precise approach for creating unique genetic variations without using novel, nonhost genes. Gene editing is a range of procedures that target particular genetic alterations in an organism's native genome (Spicer & Molnar 2018). This results in a cell or complete organism with particular genetic alterations in native gene sequences without requiring nonhost transgene DNA to be incorporated into the genome. Instead, molecular tools and techniques produce a double-strand break in the DNA sequence at a specific predefined position in the genome (Angelisa and Stefanie 2019).

Selective breeding and genetic transformation of agricultural livestock have happened for millennia, with structured breeding programs in operation for most species for years. The results have been astounding; for example, selective breeding has resulted in a threefold improvement in milk production efficiency in cows, with equivalent gains for other target qualities (Van 2017). On the other hand, modern selective breeding efforts support relatively little aquaculture productivity (Gjedrem et al. 2012). Most farmed aquatic species are still supplied from the wild or are in the early stages of domestication, implying that there is significant remaining genetic diversity for economically essential features. Furthermore, aquatic species' reproductive biology can be suitable for applying genetics and breeding technology, allowing for high selection intensity and, hence, genetic gain.

The reproductive output of genetically enhanced brood stock combined with the ease of transporting eggs and juveniles implies that better stocks can quickly impact productivity. Furthermore, with the development of high-density SNP arrays and routine genotyping by sequencing (Robledo et al. 2018), genomic selection has become the gold standard in several globally important aquaculture sectors, providing higher selection accuracies than selection based solely on phenotypic and pedigree records (Zenger et al. 2018). However, genetic progress in selective breeding is affected by the target characteristics' heritability, the species' generation interval, and the requirement to target many qualities in the breeding aim. Moreover, effective germline modification transmission has been observed in multiple experiments so far (Table 6.1).

In order to generate in vivo mutations in aquaculture species, the CRISPR/Cas9 complex is injected into newly fertilized eggs as near the one-cell stage as feasible. Typically, mRNA encoding the Cas9 protein is injected alongside the guide (g) RNA, resulting in the high effectiveness of editing observed in numerous species so

Table 6.1 Potential application of CRISPR/Cas9 genetic modification in aquaculture systems

Species	Target gene	Trait of interest	Notable features (if any)	References
Atlantic salmon, *Salmo salar*	dnd (Dead end)	Sterility	None	Wargelius et al. (2016)
	elov-2 (ELOVL fatty acid elongase 2)	Omega-3 metabolism	None	Datsomor et al. (2019)
Tilapia, *Oreochromis niloticus*	gsdf (gonadal somatic cell-derived factor)	Reproduction	None	Jiang et al. (2016)
	aldh1a2 (aldehyde dehydrogenase family 1, subfamily A2) / cyp26a1 (cytochrome P450, family 26)	Reproduction	None	Feng et al. (2015)
	sf-1 (steroidogenic factor 1)	Reproduction	Germline transmission	Xie et al. (2016)
	Amhy (anti-Mullerian hormone)	Reproduction	None	Li et al. (2015)
	wt1a/wt1b (Wilms tumor 1 transcription factor a/b)	Reproduction	None	Jiang et al. (2017)
Sea bream, *Sparus aurata*	Mstn (myostatin; nanos2, nanos C2HC-type zinc finger 2)	Growth	None	Kishimoto et al. (2018)
Channel catfish, *Ictalarus punctatus*	Mstn	Growth	Germline transmission	Khalil et al. (2017)
	ticam1(toll-like receptor adaptor molecule 1)/rbl (rhamnose binding lectin)	Immunity	None	Elaswad et al. (2018)
	LH (luteinizing hormone)	Sterility	None	Qin et al. (2016)
Southern catfish, *Silurus meridionalis*	cyp26a1	Germ cell development	None	Li et al. (2016)
Common carp, *Cyprinus carpio*	sp7a/sp7b (transcription factor Sp7-like)/mstn(ba)	Muscle development	None	Zhong et al. (2016)
Rohu carp, *Labeo rohita*	TLR22 (Toll-like receptor 22)	Immunity	Homology-directed repair	Chakrapani et al. (2016)
Pacific oyster, *Crassostrea gigas*	Mstn	Growth	None	Yu et al. (2019)

far (Table 6.1); utilizing the Cas9 protein in place of mRNA is also successful (Khalil et al. 2017). In addition, while most research has employed nonhomologous end joining (NHEJ) to produce mutations, homology-directed repair (HDR) has been effectively used to introduce a template DNA in Rohu carp.

6.4 Interventions for Improving the Productivity and Environmental Performance of Global Aquaculture for Future Food Security

6.4.1 Environmental Sustainability

Aquaculture holds promises productivity and improved environmental outcomes if the performance gap is closed. Interventions can contribute in closing the performance gap in aquaculture globally, enhancing resource use effectiveness, financial success, and overall environmental performance (Henriksson et al. 2021). In prioritizing food security, interventions that are both financially feasible for most farmers are sufficiently scalable to effect global change must be pursued. Broadly, the key interventions crucial for improving farm environmental performance can be categorized under species selection, genetic improvements, farm technologies and practices, spatial planning and access, disease control, feed, regulations and trade, post-harvest processing and distribution, and financial tools on the environmental performance of farms.

6.4.2 Species Selection

The physiology and metabolic traits of different aquaculture species vary. The productivity of different species and ecological impact also depend on species as well as specific culture conditions (Henriksson et al. 2019). Nutritional requirements for different specie range from predominantly herbivorous to almost entirely carnivorous, while some species are filter feeders. The success of farming also depends on the appropriate levels of temperature, oxygen, and salinity levels are necessary for successful cropping. Certain species of catfish (Siluriformes), for instance, can thrive in water with low levels of dissolved oxygen and have developed the ability to gulp air to compensate for their oxygen needs, which allows them to tolerate various growth conditions. Conversely, the production of species that thrive in brackish water (such as shrimp) is mainly restricted to estuary zones. Additionally social behaviour of the species also play role in determining the type farming environment required. For instance, to prevent cannibalism, solitary species like lobsters and some crabs must be raised separately. In addition to technical solutions, understanding the biology of the species is essential for captive reproduction, which is a necessary for selective breeding.

6.4.3 Genetic Improvements

Only a small proportion, approximately 10% of the world's production comes from species that have been improved through selective breeding (Gjedrem and Rye 2018). Furthermore, there are a few domesticated strains for aquaculture.

Transgenic Atlantic salmon that have been modified by replacing their growth hormone genes with Pacific Chinook salmon genes are already in the market. Other aquatic transgenic animals are being developed (Wang et al. 2021). The main long-term objectives of selective breeding are the development of morphological tolerance, edible production, appearance, disease resistance, reproductivity (age of spawning, sex ratio, and fecundity), pollution resistance, feed effectiveness, and growth rate (FAO 2019). Traditional breeding relies on the species' regeneration rate as the primary factor affecting the selection rate However the use of CRISPR (clustered regularly interspaced short palindromic repeats) have attracted attention in this regard (Gratacap et al. 2019). This method has the potential to enhance and diversity the selection rate for specific trait. However, the use is restricted by regulatory frameworks due to concerns about the food safety and environmental risks (Wargelius 2019).

6.4.4 Farm Technologies and Practices

Lakes, floating cages, fixed cages, and reservoirs for freshwater finfish and crustaceans; brackish water ponds for euryhaline crustaceans and finfish; and coastal marine floating cages, rafts, and longlines for finfish, crustaceans, and bivalves have traditionally dominated aquatic animal farming. However, in some areas, increased competition from other users, stringent regulation, negative public perception, and rising global temperatures limit aquaculture expansion (Klinger et al. 2017).

The financial viability of aquaculture largely depends on the availability of reasonably priced land and water for farming. Various unutilized regions, such as lakes and mangrove forests have been used. However, such exploitation can result in environmental harm, such as mangrove deforestation and eutrophication and cal also contribute to disease outbreaks (Henriksson et al. 2018). Developing well-designed spatial plans can be effective way to safeguard vital ecosystems, maintains ecosystem carrying capacities, and improve farm profitability. However, these plans must take into account for appropriate indicators while ensuring compliance (Bailey and Eggereide 2020).

6.4.5 Disease Control

The disease has been identified as a significant impediment to the growth of aquaculture, with the potential for severe environmental, economic, and social consequences worldwide. For instance, loss incurred due to infectious diseases is estimated to cost the global aquaculture industry $6 billion annually, with some species such as shrimp experiencing mortality rate exceeding 40% (Stentiford et al. 2017). Additionally disease contributes to excessive use of antibiotic and poor animal welfare. Nonetheless, there are various interventions that can reduce disease risks apart from selecting tolerant species and spatial planning. These interventions range from simple biosecurity measures and improved hygiene to vaccine development, specific-pathogen-free and resistant seeds. Such interventions are particularly significant in intensive systems, where stock and farm density ultimately determine disease risks.

6.4.6 Feed

Most aquatic species, especially in fed aquaculture, generally benefit from fish resources derived from reduction fisheries and processing, such as fishmeal and oil, which provide good nutrition to them. However, there are concerns regarding the sustainability of these resources, as they come from overfished stocks and be obtained using destructive fishing methods, which can be threaten for marine food webs (Zhang et al. 2020). Fisheries that target small pelagic fish generally have low carbon footprints. To address these issues, it is crucial to obtainfeed resources from certified sustainable sources. Because it would be a more efficient use of nutrients, maximizing direct human consumption of this extensive fish resource (approximately 22% of global catches) should be prioritized where demand exists or can be cultivated. There is a growing push to certify feed resources, such as the IFFO marine ingredients responsible sourcing standard and the Aquaculture Stewardship Council (ASC) Feed Standard—something that may promote better stock management but does not always lead to more effective use of these resources. Additionally, aquatic species have found it challenging to replace fish proteins in their diets although there are substitutes available, such as livestock byproducts, insect meals, ingredients derived from terrestrial plants, macro- and microalgae, and precise formulations using synthetic amino acids. However, some of these substitutes raise sustainability concerns, such as livestock byproduct meals which can shift the costs of raising cattle (including land usage and land-use change, and micronutrient supplements frequently) and have disproportionately large carbon footprints (Winther et al. 2020). On the other hand, insects are rich is nutrients (Ghosh et al. 2017; Meyer-Rochow et al. 2021), and utilization of insect meal as aquafeed has low impact on environment (Tran et al. 2021). Therefore, it is important to consider sustainability when selecting feed resources.

6.4.7 Regulations and Trade

To address the environmental and social challenges associated with the expansion of aquaculture, governments and non-governmental organizations (NGO) have implemented public and private regulatory frameworks. Third-party certification programs have gained popularity among seafood commodities due to advocacy NGOs and media campaigns, which may encourage businesses to adopt sustainable practices (Jonell et al. 2013). Upgrading value-chain and ensuring product traceability are prerequisites for driving changes in the seafood sector through certification and consumer preferences. According to DNA barcoding, up to 30% of traded seafood is mislabeled as a different species. Mislabeling can occur unintentionally due to confusion over common names and misidentification. However, most cases are likely the result of deliberate action to drive up market prices or market species that were taken unreasonably or illegally (Kroetz et al. 2020). Assigning reliable environmental profiles to aquatic foods is challenging due to misuse of even essential features such as "species." Regulations have been seen as a barrier to potential grow-out sites, therapeutics, fresh water access, effluent discharge, the use of genetically modified organisms (GMOs), non-indigenous species, and novel feed ingredients. However, regulations can address a wider range of farms and farming practices comprehensively. In general, edible yields refer to the proportion of seafood consumed, which varies from 10% for some bivalves to 100% for some small fish and sea cucumbers (Ziegler et al. 2016).

6.4.8 Financial Tools

Small scale farmers often have limited access to capital, which restricts them to improve their farms by purchasing high-quality feed, seeds, and disease diagnostics. Furthermore, they are unlikely to experiment with new farming techniques because they are risk-averse. To address this issue, insurance companies and cooperatives might play significant roles in helping smallholder aquaculture producers reduce risk and access loans and markets (Watson et al. 2018). In addition, cooperatives may enhance infrastructure utilization and reduce overall environmental impacts. By focusing on the upscaling the production of a small number of species, there may be better access to shared infrastructure, better fry, less expensive food, and markets.

6.5 Nanotechnology: A Tool for Future Aquaculture Technology

Nanotechnology exhibits tremendous potential in agriculture and allied fields like aquaculture and fisheries. Applications of nanotechnology in the fish processing industry include the detection of fish bacteria, enhancing more robust flavors, color quality, and safety by increasing the protection properties (Shah and Mraz 2020). Nanoparticles are considered delicate instruments with various uses, including medication delivery, therapy, illness diagnostics, and immunization. The primary determinant of population stability is an organism's capacity for reproduction. The fish have been successfully bred in captivity using various reproductive techniques up to this point, but the expected performance has not been attained. The ability of higher animals to reproduce has been dramatically altered by nanotechnology, and this technology also holds enormous promise for the aquaculture industry. The application of nanotechnology in fish breeding and reproduction is restricted to transferring medications, hormones, vaccines, or genes, but there is still a vast amount of unexplored territory. Due to increased impact of environmental pollution and climate change on fisheries, maintaining fish health has become more challenging (Zhang et al. 2016). Preventing pathogens and reducing disease loads are critical for effective fisheries health management. In this regard, nanotechnology offers potential solutions including fish illness diagnosis, nano-technology based fish medicine, and nanoparticles–mediated drug delivery to fish, etc. better than traditional methods (Kaul et al. 2018).

6.6 Conclusion

Aquaculture has raised considerably in recent decades with the stalemate of catch fisheries landings. It has become a crucial and robust industry worldwide, especially shrimp business, which is driven by the private sector. Good governance and policies are critical to ensuring the industry's sustainability and creating an enabling environment for private-sector entrepreneurs and small-scale producers. Aquaculture can increase its contribution to seafood supply and food security, with crustaceans providing a significant source of protein and income for those involved in the value chain. Production (as food and aesthetic items) and trade, and export of high-value crustaceans contribute significantly to the food security and economic empowerment.

Genetically altered feed ingredients and fish can potentially improve the aquaculture business, eventually easing pressure on wild fish populations, preserving natural aquatic ecosystems, and improving the nutritional profile of farmed fish for human consumption.. However, this presents significant obstacles, including consumer acceptance, environmental danger, food safety, fish welfare, and justice for aquaculture farmers. Thus an international framework for open conversation among stakeholders like national regulators, scientists, farmers, industry, and international organizations is essential for developing ways toward sustainable food and nutrition security.

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Part II
Environmental Concern and Food Safety

Chapter 7
Carbon Sequestration in Agroforestry and Horticulture Based Farming Systems: Mitigating Climate Change and Advancing Food and Nutrition Security

Abhishek Raj and Manoj Kumar Jhariya

7.1 Introduction

Increasing burgeoning population necessitate the food requirement that leads to increasing pressure on natural resources *i.e.*, forests and soils resulted various anthropogenic activities such as deforestation and illicit felling of trees for agricultural land expansion, practices of intensive farming systems by higher synthetic inputs and in parallel promotion of several industrial developments have various deleterious released greenhouse gases (GHGs) into the atmosphere causing global warming and climate change (Meena et al. 2022; Yadav et al. 2022; Jhariya et al. 2022). On other side, the practices of intensive agriculture enhance the food products by intensifying soils through heavy synthetic inputs which satisfy the food requirement of burgeoning populations but nutrient availability in fruits and foods are low which affects the people's health and livelihoods (Banerjee et al. 2020). No doubt, food availability is more but irrespective of nutrient availability and quality under the practices of intensive agriculture system which is treated as unsustainable land use systems that affects both food and environmental security. In this context, both agroforestry systems (AFs) and horticulture-based farming systems (HBFs) are good strategies to improve peoples and environment health by providing quality and nutritive foods and absorption of atmospheric carbon (C) through C sequestration. Definitely, agroforestry will stand for climate change mitigation by sequestrating more to more C from the atmosphere through the process of C sequestration and maintain ecological stability (Nair et al. 2011; Raj et al. 2020a, b). The storage and

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sequestration potential are reported maximum in the region characterizing high rainfall of humid tropic and observed in between 0.3 and 15.2 Mg C/ha/year (Nair et al. 2011). Similarly, HBFs is not less and gain a wide recognition in term of climate change mitigation by high potential of C absorption and maintaining a greater stability of C balance in the environment along with sustainability in both agriculture and natural resources.

Agroforestry is well-known sustainable land use and location specific farming system and proven itself for diversified products, higher productivity from better interaction in tree-crop-soil combination, better soil health & quality, maintaining food and nutritional security (FNS), improving farmer's health and wealth through diversified products, and overall climate security through the better potential of C sequestration in the tropics (Jhariya et al. 2019a, b). A schematic model of agroforestry technology is depicted in Fig. 7.1.

Adoption of ecological and sustainable based intensification in AFs and HBFs can operationalized these farming practices in more efficient in term of intensifying ecosystem services by enhancing biodiversity with less synthetic inputs and less emission of GHGs into the atmosphere that helps in producing diversified multiple products with nutrient rich food and fruits which maintains people's health and environmental quality (Jhariya et al. 2015; Singh and Jhariya 2016; Roy et al. 2022). In this context, this chapter describes the scope, possibilities, adoptability and conceptual framework of different models in agroforestry and HBFs along with its C sequestration potential in the tropics of the world. Moreover, soil fertility, rhizosphere biology and nutrient sink capacity through the potential of C sequestration in

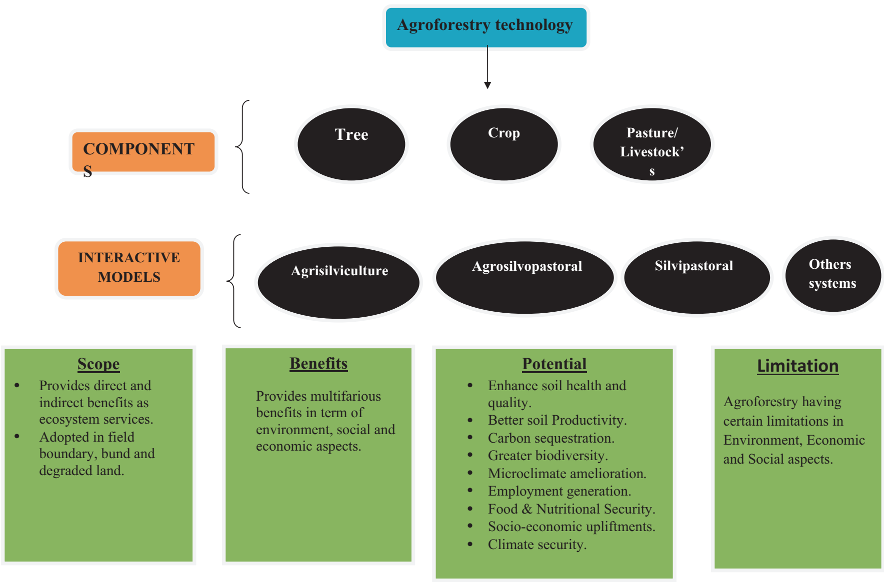

Fig. 7.1 A schematic model of agroforestry. (Compiled from: Raj et al. 2020a, b; Banerjee et al. 2020; Jhariya et al. 2015, 2019a, b)

both AFs and HBFs are also discussed. In nutshell, this chapter is designed to gather a comprehensive detail regarding various models of agroforestry and HBFs, its C sequestration capacity, related improvement of soil health and quality and overall its role in maintaining food, nutrition, health and climate security as well as sustainability.

7.2 Carbon Sequestration: Global Overviews & Historical Development

Indeed, a question always triggered among the scientific community "*is C a friend or foe*?". However, various thoughts and wisdoms are arising on this topic but it is clear that C represent itself as an important constituent of the existing ecosystems that found in different forms especially carbon dioxide (CO_2) and directly or indirectly connected with delivery of important ecosystem services for wellbeing of humans and environment (Raj et al. 2019a, b). Movement of C (*i.e.* C cycling) along with other material and gaseous cycling (water, phosphorus, nitrogen and sulphur) intensify the ecosystem services through enhancement of biodiversity (both flora and fauna), biomass accumulation, improving net primary productivity, climate moderation, etc. But now, the day came and the efficiency of C cycling along with others are greatly affected due to several anthropogenic activities which directly or indirectly ruin our environment through depriving ecosystem services (Samal et al. 2022). Emissions of excessive C in the form of CO_2 into the atmosphere are a greater challenge of all developed and developing countries. However, we can say C is a *"friend"* for somewhat extent but its excessive form of emissions and unbalance proportions in the environment put to rethink over it and consider it as *"foe"*.

In the past especially before the pre-industrial era, the proportion and percentage of CO_2 was optimum and balanced among the varying components of environment but now it is rising and today, an unstoppable emission of C (in the form of CO_2) into the atmosphere is becoming global concern for all researchers, scientists, stakeholder, policy makers, etc. due to its characteristics of GHGs.

Emission of GHGs has become a hot topic for all researchers and policy makers at global level. Gases such CO_2, methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and water vapor (H_2O) are considered as GHGs which is continuously emitted by several industrial developments, faulty land use practices, intensive farming systems in agriculture, heavy use of transportation systems, electricity consumptions and various commercial and residential activities that have deleterious impact on biodiversity which causes jeopardizing of our environment and ecosystems services. However, declining fruits quality due to lesser nutrients content, shortage of food-grain production, unexpected and untimely fruits and food production, insect pest emergence in agriculture, forestry and fruits orchards, depleting soil nutrients, less nutrient use efficiency, and overall morphological, physiological and anatomical disorders in plants are continuously observed due to emissions of various GHGs from different sectors which affects our dreams of FNS and climate security. In this context, storage and sequestration of C in environment and its components (lithosphere, hydrosphere and biosphere) are playing an important role in C balance and biomass productions (Awasthi et al. 2022; Manral et al. 2022; Thakrey et al. 2022). However, C sequestration in varying natural resources such as forest, agriculture, agroforestry, soils, etc. are a great topic to discuss which helps in better understanding and exploration of C sink capacity in the era of global warming and climate change (Prasad et al. 2021a, b; Meena et al. 2021).

Consequently, soil C sequestration gained an important attention by policymakers, national and international organization over the world. For example, "The year of soil" and "Decades of soil (year in between 2015 and 2024)" are important declaration of which the first was made by United Nations (UN) in the year 2015 and second was made by International Union of Soil Sciences (IUSS), respectively. However, the same IUSS has declared World Soil Day (WSD) with the simultaneous effort of Thai government on the occasion of World Congress of Soil Science in the year 2002. Moreover, the year 2015 was also remarkable for C sequestration due to approval of "4 per thousand" concept/resolution in the occasion of COP21 that was held in Paris. Although, the concept behind this resolution was sequestration of C in the soil ecosystem must be in depth of 40 cm with 0.4% rate in per year. That was something remarkable. However, maintaining global food and climate security along with promotion of sustainable development are defined objectives of C sequestration.

7.3 Agroforestry System and Horticulture Based Farming Systems (HFS): An Ecological Perspective

Of all-natural resources, agroforestry is more dynamic and diversified farming system which designed to make ecologically more stable and sustainable that comprises three elements (tree, crop and livestock's) in complex manner, able to sustain and feeds by diversifying productions, intensify ecosystem services, maintaining soil, food, nutrition and climate security along with enhancing both socioeconomics and other environmental benefits (Leakey 1996). The practices of AFs are widely recognized by farming communities due to its numbers of positive signs such as a greater tree-crop-livestock's interactions, sustainable land management practices, multifarious benefits, biodiversity management, varying ecosystem services, economically viable, socially acceptable, maintaining soil health and quality, enhancing flora and fauna populations, and improving food, nutritional and climate security that promotes ecological sustainability in the tropics (Cole 2010). AFs delivered various ecosystem services along with multiple products and tangible and intangible benefits such as timber, fuelwood, fodder for livestock's and NTFPs (non-timber forest products) are considered as tangible (direct) benefits whereas biodiversity enhancement, soil fertility improvement, watershed management, FNS along with climate security are represented as intangible benefits (indirect benefits). However, due to scanty of quality and nutritive food and fruits HBFs is practiced by integrating various fruit tree species, vegetables, flowers and others. It does not only help in diversifying the nutritive and quality fruits but also maintain the health status of peoples and environment. Similarly, the horticultural land systems are developed by incorporating mixed horticultural vegetable, fruits, flowers and spices crops and these are categorized into fruits namely banana (*Musa paradisica*), pineapple (*Ananas comosus*), Mandarin orange (*Citrus reticulata*), passion fruit (*Passiflora edulis*), cashew nut (*Anacardium occidentale*), etc.; vegetable crops namely cowpea (*Vigna unguiculata*), cabbage (*Brassica oleracea*), French bean (*Phaseolus vulgaris*), radish (*Raphanu ssativus*), mustard (*Brassica nigra*), ash gourd (*Benincasa hispida*), cauliflower (*Brassica oleracea* var. botrytis), pumpkin (*Cucurbita pepo*), tomato (*Solanum lycopersicum*), chow-chow (*Sechium edule*), brinjal (*Solanum melongena*), okra (*Abelmoschus esculentus*), colocasia (*Colocasia esculenta*), etc.; different spices crops such as turmeric (*Curcuma longa*) and ginger (*Zingiber officinale*), etc.; and flowers namely orchids (family, Orchidaceae), rose (*Rosa chinensis*) and anthurium (*Anthurium andraeanum*), respectively. Further, various fruit trees that used in HBFs in different agro-climatic zones of India is depicted in Table 7.1 (Singh and Jhariya 2016).

Table 7.1 Fruit tree used in horticulture-based farming systems (HBFs) in India

Agro-climatic zones	Fruit trees used in HBFs	Regions
Western Himalayan region (Reported as largest region of Indian Himalaya)	*Prunus dulcis* (Almond) *Prunus armeniaca* (Apple apricot) *Prunus avium* (cherry) *Prunus persica* (peach) *Prunus domestica* (plum) *Fragaria ananassa* (strawberry) *Juglans regia* (walnut)	Distributed in the regions of Himachal Pradesh (H.P.), J&K and Uttarakhand
Eastern Himalayan region	*Citrus sinensis* (Orange) *Musa paradisiaca* (Banana) *Prunus avium* (cherry) *Citrus limon* (Lemon) *Carica papaya* (Papaya)	Distributed throughout the North Eastern regions of India and some part of West Bengal (W.B.)
Lower Gangetic plain region	*Mangifera indica* (Mango) *Psidium guajava* (Guava) *Litchi chinensis* (Litchi)	Some part of West Bengal (W.B.)
Middle Gangetic plain region	*Mangifera indica* (Mango) *Carica papaya* (Papaya) *Psidium guajava* (Guava) *Syzygium cumini* (Jamun) *Litchi chinensis* (Litchi)	Northern region of Uttar Pradesh (U.P.) and Bihar
Upper Gangetic plain region	*Mangifera indica* (Mango) *Psidium guajava* (Guava) *Syzygium cumini* (Jamun) *Carica papaya* (Papaya) *Prunus persica* (Peach)	Throughout the Uttar Pradesh (U.P.)

(continued)

Table 7.1 (continued)

Agro-climatic zones	Fruit trees used in HBFs	Regions
Trans Gangetic plain region	*Mangifera indica* (Mango) *Phyllanthus emblica* (Aonla) *Psidium guajava* (Guava) *Citrus reticulata Blanco* (Kinnow)	Regions of Delhi, Punjab, Haryana, Rajasthan and Chandigarh
Eastern plateau and hills region	*Mangifera indica* (Mango) *Psidium guajava* (Guava) *Malus domestica* (Apple) *Phyllanthus emblica* (Aonla) *Citrus limon* (Lemon) *Punica granatum* (Pomegranate) *Carica papaya* (Papaya)	Regions of West Bengal (W.B.), Jharkhand, Chandigarh, Madhya Pradesh (M.P.), and in some parts of Odisha and Maharashtra.
Central plateau and hills region	*Mangifera indica* (Mango) *Phyllanthus emblica* (Aonla) *Ziziphus mauritiana* (Ber) *Citrus reticulate* (Mandarin orange)	Covering three states viz., Madhya Pradesh (M.P.), Rajasthan and some parts of Uttar Pradesh (U.P.).
Western plateau and hills region	*Mangifera indica* (Mango) *Carica papaya* (Papaya) *Musa paradisiaca* (Banana) *Vitis vinifera* (Grapes) *Citrus limon* (Lemon) *Citrus reticulate* (Mandarin orange) *Punica granatum* (Pomegranate)	Distributed in the regions of Madhya Pradesh (M.P.) and Maharashtra.
Southern plateau and hills region	*Mangifera indica* (Mango) *Psidium guajava* (Guava) *Musa paradisiaca* (Banana) *Citrus limon* (Citrus) *Vitis vinifera* (Grapes) *Manilkara zapota* (Sapota)	Mostly covered the southern region of Tamil Nadu and Andhra Pradesh (A.P.)
East coast plains and hills region	*Mangifera indica* (Mango) *Malus domestica* (Apple) *Musa paradisiaca* (Banana) *Annona reticulate* (Custard apple) *Manilkara zapota* (Sapota)	Covered the regions of Tamil Nadu and Andhra Pradesh (A.P.) and in some parts of Odisha and Pondicherry.
West coast plains and ghat region	*Mangifera indica* (Mango) *Citrus limon* (Citrus)	Distributed throughout the southern regions of Tamil Nadu, Karnataka and Kerala, whereas in some parts of Maharashtra, and Goa.
Gujarat plains and hills region	*Mangifera indica* (Mango) *Musa paradisiaca* (Banana) *Phoenix dactylifera* (Dates) *Vitis vinifera* (Grapes) *Psidium guajava* (Guava) *Manilkara zapota* (Sapota)	Mostly covered the western parts of Gujarat, Dadra and Nagar Haveli and two union territory regions of Daman and Diu.

(continued)

Table 7.1 (continued)

Agro-climatic zones	Fruit trees used in HBFs	Regions
Western dry region	*Ziziphus mauritiana* (Ber) *Citrus limetta* (Mosambi) *Punica granatum* (Pomegranate) *Citrus reticulata Blanco* (Kinnow)	Mostly covered the region of Rajasthan
Island region	*Mangifera indica* (Mango) *Carica papaya* (Papaya) *Manilkara zapota* (Sapota)	Distributed throughout the regions of Lakshadweep (union territory) and Andaman and Nicobar Islands (A&N)

Compiled from: Singh and Jhariya (2016)

7.4 Agroforestry Systems in the Tropics of Developed and Developing Countries

The area of AFs is not confined and limited but it spreads up to 1023 m ha globally (Nair et al. 2009a, b) of which India covered 25.32 m ha (Dhyani et al. 2013) whereas 8.0 million ha area was covered by homestead garden in Southeastern Asia (Kumar 2006) and in the U.S.A. around 235.2 million ha area was covered by silvopastoral system, hedgerow cropping, windbreaks and other riparian buffers (Nair and Nair 2003). Similarly, as per CAFRI (Janshi) and Bhuvan LISS III, around 13.75 million ha area covered under AFs in India (Rizvi et al. 2014).

Agroforestry is practicing in the tropic from a time immemorial and committed for multifarious benefits through delivering a better ecosystem services which is possible by adoption of wide array of scientific practices and management to understand better tree-crop-animal's interactions along with promising soil and climate security. In turn an improved soil quality and better environment can enhance the agroforestry performance in the tropics. In this context, a model is developed for understanding the synergy exists between environment and soil for agroforestry performance in the tropics which is depicted in Fig. 7.2 (Sun et al. 2017). It is quite interesting to know that, AFs is very flexible, location specific and can adopt easily in the varying regions of the tropics (tropical, temperate and humid regions); although it can be modifies by varying biophysical, topography, socioeconomics and climatic situations but wherever adopted it work more efficiently. Of the tropics, tropical region comparatively more promising in term of suitability, adoptability and diversity of agroforestry models than humid and temperate regions. However, many models have been developed and distributed constantly in both developing (Asian and African continent) and developed countries (European continent) of the world due to its decade of development (King 1987). Similarly, feasibility and interactions among tree-crop-animals, natural resource availability, land features, soil (edaphic) characteristics and climatic situations decide the type of agroforestry models *viz.*, agrisilvicultural, silvipasture and agrisilvopastoral, etc. varied from arid to humid tropics which is depicted in Table 7.2.

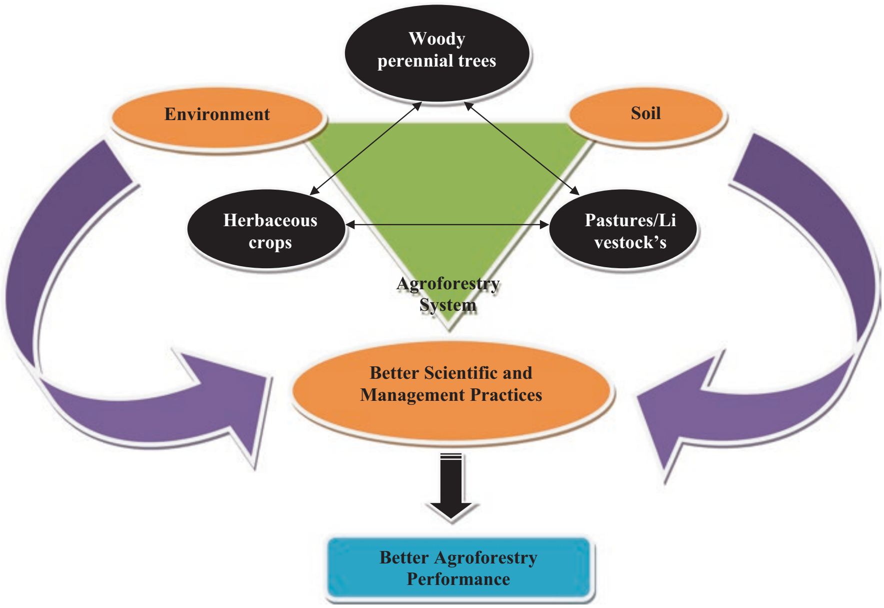

Fig. 7.2 Synergy between environment and soil for agroforestry performance in the tropics. (Compiled from: Sun et al. 2017)

Table 7.2 Agroforestry models in different tropics of the world

	Humid tropic	Arid tropic	Highland tropic
Areas	It is distributed in the regions of South-east Asia, African continent and Central America.	Mostly covered the area of Indian subcontinent, some parts of savanna and Sahara region of Africa and S. America.	Mostly covered Indian Himalayan region, South-eastern Asia, and some parts of Central Africa.
Climatic situations	Climate is typically humid with less hot condition and higher rainfall (>1000 mm). Soil order is generally Oxisols and Ultisols types.	Climate is typically hot arid with less rainfall (<1000 mm) and Soil order is generally Entisols, Vertisols and Alfisols.	This region is characterized by humid and cold climate and Soil order is generally Andosols, Oxisols, and Ultisols types.
Prefer models	This tropic having variety of models such as homestead gardens, alley cropping systems, plantation crop-based combinations and multitier tree gardens systems.	This tropic having variety of models such as silvopastoral based AFs, wind-break system, shelterbelts and model comprising various MPTs on agricultural farms.	This tropic highly recommended for silvopastoral based AFs, plantation crop-based combinations and model practices for soil-water management and conservations etc.

7.5 Carbon Sequestration Potential in Different Agroforestry Models

Sequestering atmospheric C and its fixation into both vegetation and soil helps in mitigating the global issue of climate change besides adding biomass into the woody vegetation. However, C sinks potential of AFs depend on nature and types of woody perennial tree species and associated herbaceous crops that represents tree-crop interactions and their management practices. Likewise, C allocation pattern in different components of tree species are also varies for example, the value of C content in tree branches was similar to stem but higher than root part which is followed by foliage and stem bark whereas the same C value was similar in *Acacia nilotica*, *Eucalyptus tereticornis*, *Butea monosperma* and *Azadirachta indica* followed by *Dalbergia sissoo* = *Albizia procera*, and *Anogeissus pendula* = *Emblica officinalis* respectively (Prasad et al. 2010). Similarly, Murthy et al. (2013) have estimated around 12–228 and 68–81 Mg C/ha of agrisilvicultural system practicing in humid tropical lands and dry lowlands of S-E Asia. Also, C sinks capacity of AFs in different world are depicted in Table 7.3. In general, agroforestry potentially sequesters more C and gain higher biomass as compared to other sole based cropping (monocropping) and tree plantation systems. Moreover, C sequestration potential in tropical agroforestry systems (TAS) are varies from 12 to 228 Mg/ha and as per this estimates the projected C sequestration value is 1.1–2.2 Pg in terrestrial ecosystems by next coming 50 years through the practices of AFs in the coverage area of 585–1215 × 10^6 ha of the total earth surface (Albrecht and Kandji 2003). Similarly, integration of some nitrogen (N) fixing leguminous trees-crops-grass are also a better option for C storage and sequestration along with enhancing the N availability, fertility, and health status of both vegetation and soils in the legume-based AFs (Verchot et al. 2011; Montagnini and Nair 2012). Legume based agroforestry models helps in minimizing N_2O and CO_2 emissions into the atmosphere and makes them balance in environment for better ecosystem and ecological sustainability. This will help in mitigating climate change issues and maintains the health of overall agroecosystems (Jhariya et al. 2018). Similarly, the silvopastoral system has potential to enhance greater biomass rather than sole based system. For example, the value of overall biomass was higher by 35.0% in silvopastoral system (*Azadirachta indica* + *Cenchrus ciliaris*) rather than neem sole based system. This would help in better understanding of silvopastoral potential role in biomass enhancement along with several other ecosystem services for better ecosystem (Mangalassery et al. 2014).

In nutshell, AFs represents itself as a C farming system due to its huge potential in capture and storage of C in both vegetation (tree-crop) and soils which requires a good management practices to improve C sink capacity that helps in producing higher biomass and maintain C balance in ecosystem for better environment and ecological sustainability (Jhariya et al. 2019a).

Table 7.3 Carbon sinks capacity of agroforestry systems in different world

Different AFs in the tropics	Soil carbon sink capacity	References
Agri-silviculture based agroforestry model comprising *Gmelina* tree in Chhattisgarh state of India	30.20 US ton ha^{-1}	Swamy and Puri (2005)
Homestead/Kitchen garden system in Panama City of central and South America	49.6–2.5 US ton ha^{-1}	Kirby and Potvin (2007)
Homestead/Kitchen garden system in African continent	220.5 US ton ha^{-1}	Nair (2012)
Silvopastoral based AFs in African continent	1.65–3.85 US ton ha^{-1}	
Alley-cropping system comprising tree as *Populus deltoides* and crops as soybean, wheat and maize in Canada	1.38 US ton ha^{-1}	Oelbermann et al. (2006)
Silvopastoral based AFs comprising tree as *Pinus elliottii* and grass (*Paspalum notatum*) in USA	7.60–26.7 US ton ha^{-1}	Haile et al. (2008)
Mixed tree stands system in Puerto Rico		
Casuarina and *Eucalyptus* based mixed tree stands in Puerto Rico, U.S.A.	68.23 US ton ha^{-1}	Parrotta (1999)
Casuarina and *Leucaena* based mixed tree stand in Puerto Rico, U.S.A.	62.39 US ton ha^{-1}	
Leucaena and *Eucalyptus* based mixed tree stands in Puerto Rico, U.S.A.	68.01 US ton ha^{-1}	
Silvopastoral based AFs comprising tree *Quercus suber* (commonly known as cork oak) in Spain	29.21–55.3 US ton ha^{-1}	Howlett (2009)
Silvopastoral based AFs comprising tree *Betula pendula* in Spain	146.6–165.3 US ton ha^{-1}	Howlett et al. (2011a, b)
Silvopastoral based AFs comprising tree species like *Eucalyptus* along with a grass *Brachiaria* species in the region of Brazil	389.1 US ton ha^{-1}	Tonucci et al. (2011)
Silvopastoral based AFs in USA	564.4 US ton ha^{-1}	Haile et al. (2010)
Alley-cropping system comprising tree species as *Populus deltoids* commonly known as poplar in Canada	62.83 US ton ha^{-1}	Bambrick et al. (2010)
Agri-silviculture based model comprising *Poplar* in Punjab, India	10.4 US ton ha^{-1} yr^{-1}	Chauhan et al. (2010)
Agri-silviculture based model comprising *Subabul* in Andhra Pradesh, India	3.05 US ton ha^{-1} yr^{-1}	Rao et al. (1991)
Silvopastoral based AFs comprising tree species *Acacia nilotica* (babul) in Haryana region of India.	3.09 US ton ha^{-1} yr^{-1}	Kaur et al. (2002)
Kerala based homestead garden in India	1.76 US ton ha^{-1} yr^{-1}	Saha et al. (2009)
Agri-silviculture based model comprising tree species *Casuarina equisetifolia* in the region of Tamil Nadu, India	1.73 US ton ha^{-1} yr^{-1}	Viswanath et al. (2004)

(continued)

Table 7.3 (continued)

Different AFs in the tropics	Soil carbon sink capacity	References
Silvopastoral based AFs comprised *Brachiaria brizantha* (commonly known as bread grass) as fodder species intercropped with species such as *Guazuma ulmifolia* (bay cedar) and *Cordia alliodora* (salmwood) in the region of Costa Rica	145.5 US ton ha^{-1}	Amezquita et al. (2005)
Silvopastoral based AFs comprised tree species *Acacia mangium* (commonly known as black wattle) intercropped with fodder species of *Arachis pintoi* in the region of Costa Rica	190.7 US ton ha^{-1}	
Agri-silviculture based model comprised poplar tree and *Hordeum vulgare* (barley)as agriculture crop in Canada	86.5 US ton ha^{-1}	Peichl et al. (2006)
Agri-silviculture based model comprised *Pseudotsuga menziesii* (commonly known as Douglas fir) tree species intercropped with *Trifolium subterraneum* (native to Northwestern Europe) in the region of USA	105.8 US ton ha^{-1}	Sharrow and Ismail (2004)
Alley-cropping system comprising tree as Subabul (*Leucaena leucocephala*) in western region of Nigeria in the African continent	14.9 US ton ha^{-1}	Lal (2005)
Pterocarpus and *Gliricidia* based protein bank/ fodder bank system in the region Mali	36.81 US ton ha^{-1}	Takimoto et al. (2008)
Agri-silviculture based model comprised N fixing *Gliricidia* trees intercropped with *Zea mays* (maize crop) in the region of Malawi	135.6 US ton ha^{-1}	Makumba et al. (2007)

7.6 Soil Carbon Sequestration in Agroforestry Systems: A Global Scenario

Soil, as we call "*soul of infinite life*". Yes, it is true and can't be denied due to sustaining whole life by supporting biodiversity (tree, crop, animals and other natural resources), anchoring tree roots, harboring various soil inhabiting flora and fauna including beneficial micro-organisms, stores essential nutrients, maintain rhizosphere populations, and deliver multifarious ecosystem services to maintain ecosystem structure. However, better management practices in AFs and soils could be helpful in enhancing C value through effective sequestration process (Raj et al. 2020a, b). Addition and decomposition of litter fall, twigs, barks and other tree's fallen residues/materials can enhance the C content value that directly and indirectly increase the population of earthworm and soil inhabiting beneficial microorganisms and their interactions will improve the fertility and health status of soils (Bertin et al. 2003). Moreover, tree species, their types, nature, tree-crop interactions, shedding leaf litters, its texture and decaying rate along with agents that involve in decompositions will surely affects the extent of C accumulation, sink capacity and C release into the soils. Similarly, management practices in AFs also add some inputs in C addition which reflects health status of soils (Jhariya et al. 2019b). However, tropical soils contributed higher biomass, more C contents and diverse form of microorganism as compared to temperate soils. Thus, soil C-sequestration value in different AFs in the world is depicted in Table 7.4.

Moreover, integrating tree with some pasture/grass species (known as silvopastoral system) are gaining wide recognition for reclamations of degraded land and having great potential of C sink either into vegetation and soils that help in biomass increment and improvement of soil fertility. Silvopastoral system can store more organic C into the soils through greater potential of C sequestration. In addition, integrating leguminous N fixing multipurpose tree (MPTs) with some valuable pastures could be a great option to minimize GHGs emission and climate change mitigation along with diversifying products (as timber, fuelwood, fodder for livestock's, etc.), intensifying ecosystem services and maintain N and C status into the soils for better ecosystem. Therefore, this system can be going in the direction of improving higher biomass, soil organic C and N availability. Legume trees such as Acacia species and subabul (*Leucaena leucocephala*) have great capacity to capture and fix C into soils that can be stored in the form of soil organic carbon (SOC) as a pool which

Table 7.4 Soil carbon-sequestration value in different agroforestry systems in the world

Agroforestry practices including species	Areas	Depth of soil (cm)	Soil carbon value (Mg/hectare)	Author
Different forms of mixed stands system comprising *Casuarina* and *Eucalyptus* species, *Leucaena* and *Casuarina* species, and *Leucaena* and *Eucalyptus* tree species of 4 years aged	Distributed in Puerto Rico	0–40	Soil C value of these three combinations were 62, 57, and 62 respectively.	Parrotta (1999)
AFs comprised agrisilviculture model having tree (*Gmelina arborea*) and different eight agricultural crops of total 5 years aged	Covered most part of Chhattisgarh state in Central India	0–60	Soil C value was 27.4	Swamy and Puri (2005)
Homestead gardens	Practiced in the region of Ipet_-Embera, Panama	0–40	Soil C value varied in between 2.3 and 45	Kirby and Potvin (2007)
Silvipasture models having *Pinus elliottii* (slash pine) and *Paspalum notatum* (bahia grass) of total 8–40 years old aged	Practiced in the region of Florida (USA)	0–125	Soil C value varied in between 7 and 24.2	Haile et al. (2008)
Hedgerow intercropping system having varying combination of hybrid poplar (*Populus deltoids*) + wheat crop, soybeans (*Glycine max.*) and maize (*Zea mays*) of total 13 years old	Practiced in the most part of South Canada	0–40	Soil C value was 1.25	Oelbermann et al. (2006)

improve the fertility and health status of tropical soil (Cadisch et al. 1998). Moreover, combination of *Leucaena leucocephala* and *Dalbergia sissoo* could potentially sequester more C as compared to sole based plantation system that can help in combating global warming and climate change issues (Sheikh et al. 2015). Similarly, integrating legume trees with eucalyptus tree-based plantation were worked more effectively in term of storage and sequester of C into the soils (Kaye et al. 2000). However, many studies were conducted for better understanding of the potential role of silvopastoral system (rather than monocropping/sole based cropping system) in SOC enhancement through better C sequestration as compared and its role in climate change mitigation. For example, the value of SOC was increased from 36.30% to 60% in silvopastoral system (*Azadirachta indica* + *Cenchrus ciliaris*) rather than sole cropping system (Mangalassery et al. 2014). Moreover, C sinks value in soil of different silvopastoral systems are depicted in Table 7.5. As per one estimate, well managed silvopastoral model has potential to sequester approximate 0.012 TgC/ha and predicted value is 0.6 TgC/ha up to the year 2040 by converting 630 m ha degraded croplands/grassland system into AFs (Kirby and Potvin 2007; Ghosh and Mahanta 2014).

Table 7.5 Silvopastoral systems and its carbon sink value in different parts of the world

Silvopastoral models in the regions	Carbon sink value	References
This model comprises jaragua grass (*Hyparrhenia rufa*) as a grass species prevalent in the region of Nicaragua, Central America	C sink value was 150 Mg C/ha in the soil at 0.6 m depth.	Ruiz et al. (2004)
Practiced in the same region of Nicaragua, Central America where three grass species such as Guinea grass (*Panicum maximum*), palisade grass (*Brachiaria brizantha*) and dhoob grass (*Cynodondactylon*) were used.	C sink capacity was 158 Mg C/ha in the soil ecosystem at certain depth.	
Woody perennial trees were integrated with jaragua grass and palisade grass in the region of Costa Rica	C sink value was varied from 3.5 in sole *Hyparrhenia rufa* grass species to 12.5 Mg C/ha in palisade grass + *Diphysarobinioides* tree species.	Andrade et al. (2008)
Incorporation of valuable fodder grass with eucalyptus tree species and other sole based eucalyptus plantation in the region of Brazilian Cerrado	C sink value in soil varied from 461 Mg/ha in pasture to 393 Mg/ha in the sole based eucalyptus plantation.	Tonucci et al. (2011)
Quercus suber (Dehesa cork oak tree) based silvopastoral system practiced in the region of Spain	It was observed C value was increased by 50.2, 37.0 and 26.5 Mg/ha as per increasing the distances of 2.0, 5.0 and 15.0 m from the tree *Quercus suber* at the depth of 1 m.	Howlett et al. (2011a, b)
Integration of N fixing *Inga feuilleei* (Inga tree species) with *Setaria sphacelata* (pasture grass) based silvopastoral system practiced in the region of Ecuadorean Andes	C sink value was increased by 8.0% and 11.4% under the *Setaria sphacelate* and *Inga feuilleei*, whereas 20 Mg C/ha was reported under Inga tree species.	Rhoades et al. (1998)

(continued)

Table 7.5 (continued)

Silvopastoral models in the regions	Carbon sink value	References
This system consisted both natural grassland and other silvopastoral models having leguminous N fixing trees such as subabul (*Leucaena leucocephala*), *Albizia* species (*Albizia amara*) and sickle bush (*Dichrostachys cinerea*) along with grasses such as *Stylosanthes hamata* (Caribbean stylo), *Chrysopogan fulvus* (Beardgrass) and *Salvia scabra* (coast blue sage), etc.	The C sink value was 6.72 ton C/ha/yr in silvopastoral which is two times more than 3.14 ton C/ha/yr in natural grassland system. This data represents that silvopastoral system has higher potential of C sequestration rather than other sole and natural grassland system.	NRCAF (2007)
Amla (*Emblica officinalis*), Eucalyptus species, *Albizia* species and Sissoo (*Dalbergia sissoo*) based silvopastoral systems practiced in natural grassland semi-arid regions of Uttar Pradesh, India.	The C storage value was 1.9–3.4 ton C/ha in silvopastoral system as compared to 3.9 ton C/ha in sole pasture/grasses system.	Rai et al. (2009)
Silvopastoral systems comprised N_2 fixing leguminous tree such as subabul (*Leucaenea leucocephala*) with buffel grass (*Cenchrus ciliaris*) and Caribbean stylo (*Stylosanthes hamata*).	The value of OC content was increased by 1.70–2.30 times in the soil.	
Practiced silvopastoral systems in wasteland/degraded areas	The value of soil C was observed in between 24.3 and 35.0 Pg (pictogram)	Narain (2008)
The system comprised both tree species (*Acacatortilis*) *and grass* (*Cenchrus setegerus*) *in the Regional Research Station (RRS) of* Kukma (Gujarat), India.	The C sink value in underground was 23.4% (1.6 ton/ha) of total pool value of C stock of the systems.	Kumar (2010)

7.7 Horticulture Based Farming Systems (HFS) in the Tropics

If we look on the statistical figure on horticultural productions and land use systems then we see around 300 m MT of productions was reported through horticulture which is quite higher than 275 m MT of agricultural grains productions. This higher production promotes per capita consumption of variety of vegetables and fruits over the period. Of this figures, perennial horticultural crops produced around 214 MT/yr from 12.1 Mha areas of which fruits, plantation crops, spices and nuts contributed 6.1, 3.2, 2.6 and 0.14 Mha areas, respectively. These figures pull the attentions of growers towards perennial horticultural crops and related land use systems due to higher production systems, maximum area coverage, low inputs of energy and water than other annual field crops in agriculture and AFs (Ganeshamurthy et al. 2020). Although, HBFs/fruit based AFs comprises various models such as agri-horticulture system (agricultural crops and fruit trees/vegetables/spices/flower crops), horti-pastoral system (Integration of different fruit trees/vegetables/spices/flower crops with livestock's/pasture), agri-horti-silviculture system (integrating three components of agricultural crops, different fruit trees and trees other than fruits), multitier horticulture system, different horticultural land use systems and homestead gardening practices that are mostly widespread in humid, arid and semiarid tropics of the world.

HBFs are playing an important role in providing various nutritious and quality fruits and vegetables and having potential to cover minimum dietary needs of both vegetables and fruits /day/capita which is 220 and 85 gram per head per day rather than available 80 and 60 gram, respectively (Roy 2011). Some fruit trees like guava (*Psidium guajava*), Indian gooseberry or amla (*Emblica officinalis*), plum (*Prunus domestica*), mango (*Mangifera indica*), apple (*Malus domestica*), papaya (*Carica papaya*) and *Citrus species*, etc. are very commonly used in different agroclimatic zones of India. As per Singh and Malhotra (2011), in rainfed regions horticulture crops add additional income along with maintaining food, nutrition and climate security.

7.7.1 Agrihorticulture (Crops + Fruit Trees)

This system comprised a simultaneous integration of agricultural crops (both annual and perennials characteristics) and fruit trees/vegetables/flower/spices, etc. in unit land and widespread in the marginal and dry areas of different agroclimatic zones mostly dominant in India, Sri Lanka, Nepal and Bangladesh (Pant et al. 2014). In this context, the recommended combination of agriculture crops with horticulture trees under agri-horticulture model in HBFs prevailed in dry region of Rajasthan is depicted in Fig. 7.3 (Bhandari et al. 2014). Also, Table 7.6 showing varying

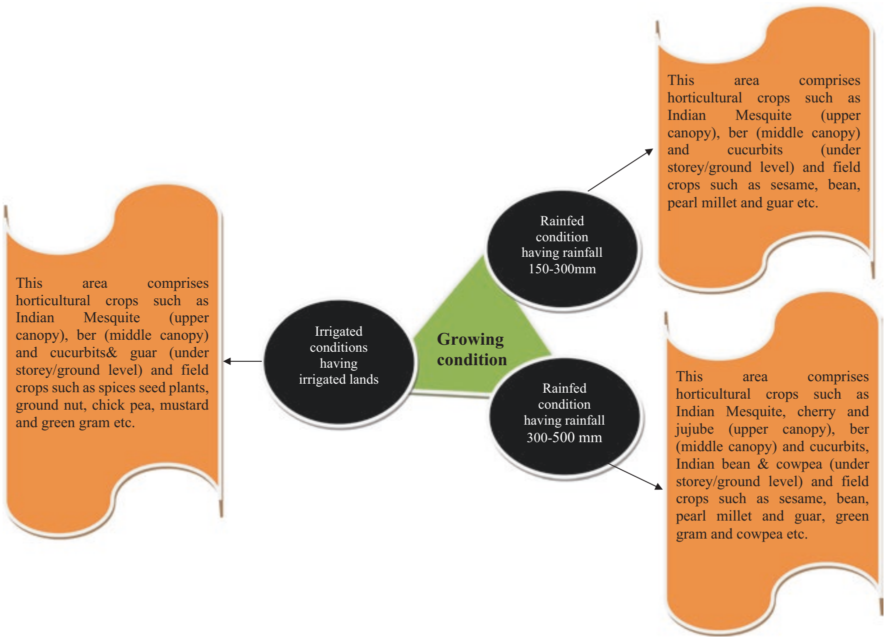

Fig. 7.3 Agri-horticulture model in Horticulture based farming system in dry region of India (Bhandari et al. 2014)

Table 7.6 Varying tree-crop combinations of agri-horticulture system practiced in agro-climatic zones of India (NRCAF 2007)

Agro-climatic zone	Tree-crop-grass component
1.Western Himalayan region	Integration of apple tree (*Malus pumila*) with the field crops such as millets and wheat
	Integration of peach tree (*Prunus persica*) with the field crops such as millets and soybean; soybean, millets
Eastern Himalayan region	Integration of alder tree (*Alnus nepalensis*) with the field crops such as coffee and cardamom.
Lower Gangetic plains	Mostly irrigated type of agrihorticulture system. Integration of mango (*Mangifera indica*), banana (*Musa paradisica*) and litchi (*Litchi chinensis*) with the agricultural crops such as maize, paddy and wheat.
Middle Gangetic plains	Mostly irrigated type of agrihorticulture system. Combination of mango and *Citrus spp.* with the agricultural crops such as wheat and rice.
Trans Gangetic plains	Mostly irrigated type of agrihorticulture system. Ecologically & economically sound combination in which Aonla (*Emblica officinalis*) is combined with green & black gram.
Central-plateau and hills	Mostly irrigated type of agrihorticulture system. This zone comprised a good combination of fruit tree *Psidium guajava* + field crops such as ground nut and Bengal gram.
	Rainfed Agrihorticulture system is practiced in this zone. Ecologically& economically sound combination in which Aonla is combined with green & black gram.
Western plateau and hills	Mostly irrigated type of Agrihorticulture system. Ecologically sound practices comprised tree components such as Teak (*Tectona grandis*) and Sapota (*Achrus sapota*) + crops such as maize and paddy.
	Combination of Indian nut palm (*Areca catechu*) + *cardamom* (*Elettaria cardamomum*) and black pepper (*Piper nigrum*) are prevalent in this agroclimatic zones.
Southern plateau and hills	A good fruit tree and crop combination comprised both Imli (*Tamarindus indica*) and chilli (*Capsicum annuum*)
West coast plains and hills	Rainfed Agrihorticulture system is practiced in this zone. This zone comprised fruit tree such as Jack fruits (*Artocarpus heterophyllus*) and black pepper (*Piper nigrum*).
	Coconut (*Cocus nucifera*) and *paddy* combination are prevalent and suited in this region as per climatic condition.
Island region	Coconut and *paddy* are also reported in this agroclimatic zone.

tree-crop combinations of agri-horticulture system is practiced in different agro-climatic zones of India (NRCAF 2007). However, this system consists short duration of juvenile fruit and vegetable plants which is sometimes combined with other MPTs, therefore it produces other products like good quality timber, fodder, fuel-wood, NTFPs in addition to food grains and horticultural produce. That's why, farmers mostly prefer agri-horticultural system rather than agri-silvicultural system due to less juvenile phase, high nutritive and quality fruits, vegetables and spices, and having good economic returns in short durations in agri-horticultural system (Kareemulla et al. 2002).

7.7.2 Hortipastoral (Fruit Trees + Pasture/Animals)

This system is highly recommended on degraded and wasteland areas due to its great reclaiming potential along with supplying nutritive and quality fruits, vegetables, highly palatable leguminous fodder/pastures (to livestock's) that maintains health status of farmers and animals (Kumar et al. 2011). However, various form of horti-pastoral models are existing namely Aonla (*Emblica officinalis*) based horti-pastoral system for conservation purpose of soil and water, Bael (*Aegla marmelos*) based hortipastoral system, Tamarind (*Tamarindus indica*) based hortipastoral system, etc. spreads in the rainfed regions, custard apple (*Annona sp.*) based hortipastoral system, Kinnow (*Citrus nobilis* × *C. deliciosa*) based hortipastoral system distributed in the partial irrigation system, etc. that enhance the biodiversity, improve ecosystem services and maintains income and health status of poor farmers and local communities in the tropics (Kumar et al. 2009).

7.7.3 Agrihortisilviculture (Crops + Fruit Trees + Tree Other Than Fruits)

The model itself represents an integration of three components such as agricultural crops, different fruit trees/vegetable crops and trees other than fruits respectively. This system nurtures all the biodiversity and maintains health, wealth, and food and climate security in every aspect. "*Is this system being more diversifies, secure and sustainable than others in HBFs*?" The answer is "yes" because having more components represents more diversity which intensified ecosystem services along with other multifarious tangible (timber, fuelwood, fodder, NTFPs, etc.) and intangible benefits in term of money, health, microclimate amelioration, soil health and quality through fertility improvement and climate change mitigation through C sequestration, etc. The peculiar significance of this system having higher possibility of income generation through mature fruit trees rather than monsoon dependable agricultural crops.

7.8 Carbon Footprint of Agriculture Versus Fruits and Vegetables Crops

The horticultural land use systems comprise various fruits and vegetable crops are having less contribution in GHGs emissions; for example, low GHGs emissions were observed in potato and other root vegetable crops due to high productivity potentials. However, Joshi et al. (2009) have predicted the annual demands for different vegetables and its contribution in global warming potential (GWP) are 127.01 Mt and 21.7 Mt CO_2 eq. whereas fruit crop like apple (*Malus domestica*) has 86.0

Mt of annual demands and 30.7 Mt CO_2 eq. of global warming potential (GWP) by the year 2020–2021. The estimated figure indicates an apple has less demands but higher contribution in GWP as compared to vegetable crops. However, agricultural food crops have more in demands and GWP value as compared to fruits and vegetables. For example, the demands (Mt) and GWP (Mt CO_2 eq.) values of wheat, rice and pulses are 83.0 and 29.1, 173.0 and 246.3, 16.0 and 15.5, respectively by the year 2020–2021. These figures are enough to say about comparative studies on demand and GWP of horticulture (fruits and vegetables) versus agricultural food crops.

Similarly, many authors have quantified GHGs emissions and related GWP (global warming potential) contribution by various agricultural and horticultural crop production through a series of field experiments at IARI, New Delhi and according to them, the vegetables crops such as potato, cauliflower and brinjal contributed in CO_2 emissions (g/kg) are in the order of cauliflower (13.3) > brinjal (12.5) > potato (10.0) whereas overall maximum potential in global warming (CO_2 eq.) are observed in brinjal (31.1) followed by cauliflower (28.2) and least value in potato (24.9), respectively. Similarly, the value of N_2O was similar as 0.1 g/kg whereas CH_4 was zero among these horticultural crops. The horticultural fruit crops such as banana, apple and other spices contributed in CO_2 emissions (g/kg) are in the order of spices (100) > apple (41.7) > banana (10.0) whereas overall maximum potential in global warming (CO_2 eq.) are observed in similar fashion i.e. spices (845.0) > apple (331.4) > banana (71.6) respectively. Similarly, the value of N_2O was highest in spices (2.5) followed by apple (1.0) and least value (0.2) observed in banana whereas CH_4 was zero among these horticultural crops (Majumdar et al. 2002; Bhatia et al. 2004; Chhabra et al. 2009; Pathak et al. 2009).

7.9 Carbon Sequestration Potential in Horticulture Based Farming Systems/Fruit Based Agroforestry Systems

It is well known fact about the potential of horticultural based land use systems in C sequestration than the other farming technology i.e. agriculture and AFs in the tropics. However, perennial crops contributed major role in CO_2 sequestration than annual crops. In this context, a study has been conducted on varying horticulture-based farming systems and it was observed that C sequestration potential was maximum in mango-based land used systems followed by cashew (*Anacardium occidentale*), rose (*Rosa chinensis*), vegetables and medicinal and aromatic plants-based land used systems. In addition, higher inputs of plant residues into the soil of perennial systems resulted into less CO_2 emission than other annual crops in agriculture systems. Somehow, perennial horticultural based farming systems helps in gaining economic benefits through C credits. Therefore, applying an effective strategy of better C management and soil health improvement would be helpful in enhancing C sequestration technology in both perennial based horticulture systems and AFs (Ganeshamurthy et al. 2020). Similarly, many studies have been conducted on different horticulture-based models for C storage and sequestration. C sequestration capacity varies as per varying horticulture land use systems. For example, agri-horticulture model has been proven a better farming practice for mitigation of CO_2 and having higher economic gain with C credits as compared to other practices like agriculture, silvopastoral and varying land use practices of forest ecosystem in the Himalaya regions (Rajput et al. 2017). Horticultural orchards having greater capacity to enhance C storage value in subsoil region than other AFs due to deep rooting characteristics in perennial orchard system. An attempt has been made to justify the question "*Is species associations affect the C sequestration potential?*" Indeed, the potential of C storage and sequestration will vary as per varying combinations of plants, its types, nature and including management practices in climatic situations. In this context, the highest C sink value (140.1 t ha^{-1}) was observed in the combination of *Cocos nucifera* (coconut tree) and *Syzygium cumini* (Jamun) which is followed by139.0 C t ha^{-1} in *Cocos nucifera* + *Mangifera indica* and least value has been observed in *Cocos nucifera* + *Garcinia indica* (Garcinia) as 132.2 C t ha^{-1} whereas coconut sole plantation reported only 98.2 C t ha^{-1}, respectively (Bhavya et al. 2017).

As we know, horti-silviculture systems are ecologically sound and diversified horticulture-based farming systems which can withstand in less moisture condition in dry region of the tropics. C sink capacity and sequestration of horticulture-based farming systems in this region will helps in enhancing C stocks in both vegetations and soils in various farming models. However, C sink capacity in any systems depends on nature and type of plant species and its sink potential in any farming systems. Various studies have been conducted on this topic; for example, Singh and Singh (2015) reported C sink values in the form of biomass C, soil C which was compared with total C values in the various tree combinations of horti-silviculture systems vs. sole tree systems in the dry region of Rajasthan. According to the study (Singh and Singh 2015) the C sink value in soil ecosystem was higher as compared to biomass C. Also, C value was observed higher value in tree combinations in horti-silviculture systems than sole tree systems due to greater diversity and sink potential of horti-silviculture rather than single cropping systems. Nutrient losses through leaching would be less in tree combinations in horti-silviculture systems due to closed type of nutrient cycling. Therefore, different trees combinations including fruit trees in horti-silviculture systems are used for a comparative study on C sink potentials in both soils and vegetation as biomass C. In this context, comparative studies of soil C and total C sink in horti-silviculture vs. sole tree systems in dry regions of Rajasthan (India) are depicted in the Fig. 7.4.

From the Fig. 7.4, it clearly demonstrates that maximum total C value (soil + biomass) was 5.07 Mg/ha reported in the combination of *Cordia myxa* + *P. cineraria* based AFs due to greater potential of C sequestration. Therefore, the capturing and storing of atmospheric C depends on tree-crop combination, its type of interaction, nature of species, feasibility of combinations and related management practices that affect the potential of C sequester into both vegetation and soil components in horticulture-based farming systems. This can be justified by Yadav et al. (2015) which demonstrated that the combination of pear (*Pyrus communis*) and wheat

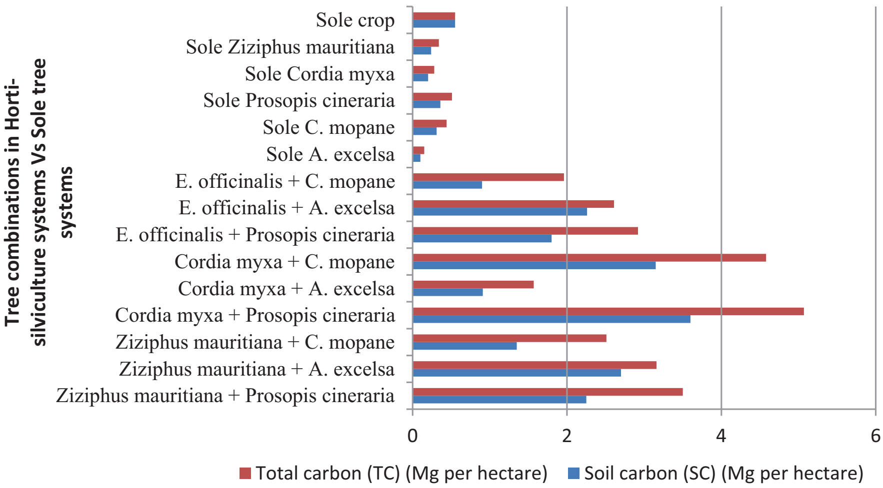

Fig. 7.4 Comparative studies of soil carbon and total carbon sink in horti-silviculture vs. sole tree systems in dry regions of Rajasthan (India) (Singh and Singh 2015)

(*Triticum aestivum*) had maximum value of biomass (38.0 Mg/ha), C storage (17.0 Mg/ha) and C stock equivalent CO_2 (62.3 Mg/ha) respectively rather than sole wheat cropping system. This result represented that combination of fruit trees with the crops having more value of biomass and C than sole based cropping system. Secondly, type and nature of horticulture tree and crop combinations and their interactions deliver the potential of biomass and C sequestration. In the same study, it found that the combination of pear and wheat has maximum rate of biomass (12.0 Mg/ha/yr), C storage (5.3 Mg/ha/yr) and C stock equivalent CO_2 (19.6 Mg/ha/yr) which is followed by other less valuable interactive combinations of apricot (*Prunus armeniaca*) + wheat having 11.5, 5.2 and 19.0 Mg/ha/yr, respectively. Thus, fruit trees under HBFs showed a significant improvement in enhancing total biomass and C sink value which needed more study for better understanding the interactions and its positive impacts on our environment.

7.10 Soil Carbon Sequestration in Horticulture Based Farming Systems (HBFs)

Horticulture based land use systems has proven itself a good C farming system due to greater potential of tapping, sequestration and storing of atmospheric C into soil that helps in reclamation of degraded lands by improving productivity along with diversity enhancement which maintains ecological sustainability (Wang et al. 2010). Especially, perennial horticultural crops having higher potential in C sequestration than agriculture and AFs (majorly annual crops) in the tropics (Shrestha and Malla 2016; Janiola and Marin 2016; Chandran et al. 2016; Bhavya et al. 2017).

Table 7.7 Soil carbon storage and carbon dioxide sequestration value (Mg/ha) under different horticulture land-use systems

Soil depth (cm)	Carbon storage & carbon dioxide sequestration value in Mg/ha	Horticulture based different land-use system of 4 years aged				
		Mango based orchard	Cashew based orchard	Rose block plantation	Vegetable based block plantation	Medicinal and aromatic based block plantation
0–15	C storage	1375.0	1244.1	1006.0	990.0	974.0
	CO_2 sequestration	5045.3	4566.0	3691.1	3633.3	3574.4
15–30	C storage	1361.2	1245.0	1004.0	973.3	954.2
	CO_2 sequestration	4996.0	4569.2	3683.3	3572.2	3502.0
30–50	C storage	1811.2	1679.5	1306.0	1308.4	1265.0
	CO_2 sequestration	6647.2	6164.0	4793.0	4802.0	4642.5
50–100	C storage	4478.2	4075.5	3215.2	3110.1	3082.3
	CO_2 sequestration	16435.0	14957.1	11801.0	11414.0	11312.0
1 m	CO_2 value	9025.4	8244.1	6530.5	6382.0	6275.5

Compiled: Bhavya et al. (2017)

However, Bhavya et al. (2017) has emphasized the importance of perennial crops in horticulture land use systems and according to the study; emission of CO_2 was less due to higher input of residues into the soil in perennial systems rather than other annual crops. Also, the C sequestration potential of different horticulture land use systems (4 years old) were reported and found in the ranked of mango-based orchard > cashew-based orchard > rose (*Rosa chinensis*) block plantation > vegetable-based block plantation > medicinal and aromatic based block plantation, respectively. Therefore, both soil C stock and CO_2 sequestration value (Mg/ha) were calculated at different depths in varying cropping systems of horticulture land use practices which is depicted in Table 7.7. Thus, perennial horticulture-based farming systems showed greater potential in C sequestration and higher soil C stocks which would be helpful in enhancing soil fertility and health (Chandran et al. 2016).

7.11 Soil Organic Carbon (SOC) & Soil Fertility in Horticulture and Other Farming System

Indeed, a great synergy exists between SOC and fertility status of soils. SOC plays an important role in global C cycle, promotes efficient nutrient cycling and maintaining soil fertility along with ecological sustainability (Lenka et al. 2017). If we compared perennial horticultural system with other annual farming system then it is clearly demonstrated that perennial systems are more efficient in C sequestration and maximum SOC than other annual cropping system that helps in enhancing soil fertility, health and mitigate our changing climate. Similarly, the value of total soil organic carbon (TSOC) was highest (29.0 Mg C/ha) in *Psidium guajava* followed by *Syzygium cumini* (27.3 Mg C/ha), *Litchi chinensis* (26.0 Mg C/ha), and least value (19.2 Mg C/ha) in *Mangifera indica* whereas the value of OOC (oxidizable organic C) was recorded maximum (26.0 Mg C/ha) in *Psidium guajava* followed by both *Syzygium cumini* and *Litchi chinensis* having same value (25.1 Mg C/ha)and least (16.5 Mg C/ha)was observed in *Mangifera indica*, respectively on reclaimed sodic soils of perennial horticultural land use systems in the tropics (Datta et al. 2015).

The rate and dynamics of C sequestration and pool stocks varies as per varying land use practices such as AFs, HBFs, horti-silvi-pastoral system, forestry and another mangrove ecosystem. As per Das and Itnal (1994) the value of SOC increased from 4.2 g/kg to 7.1 and 7.3 g/kg while converting sole cropping to agroforestry and agri-horticulture land use systems of 6 years old. The maximum value of SOC was observed under forest land which was followed by other land use systems in the rank of natural grasslands > varying fruits orchards > Eucalyptus plantation respectively in 30 cm depth of soil ecosystem. Of all these practices, fruit orchards played remarkable role in SOC pools and observed in the rank of apple > mango > litchi > citrus species > guava with respective value of SOC was 105.2, 53.2, 45.5, 43.1, 39.0 ton/ha. Thus, apple orchard has greatest potential of climate change mitigation through highest contribution in SOC pool as compared to other perennial fruit orchards (Gupta and Sharma 2011). However, different horticultural land used systems such as orchards of jamun (*Syzygium cumini*), *Psidium guajava* (guava), *Litchi chinensis* (litchi) and mango (*Mangifera indica*) have different value of SOC and highest value (133 Mg C/ha) was observed in guava orchard along with maximum (76 Mg C/ha) C content in passive pool which increased with depth in all other land used systems (Datta et al. 2015). Similarly, SOC content was highest (9.5 g/kg) in *Vicia faba* cover crop management system as compared to 8.7 g/kg in conventional tillage practices under 5 years of Mediterranean vineyards of Sicily at Italy (Novara et al. 2019). Moreover, a dense forest ecosystem has more diverse species which intended to higher sequestration of C than other land use system having sole plantation system. That's why the value of SOC at 1 m soil depth was maximum (1.29%) in dense mixed forest followed by 1.22% in horticultural plantation system and least value in agricultural system (Koppad and Tikhile 2014).

7.12 Carbon Sequestration and Nutrient Sink/Input in AFs and HBFs

One question always strikes i.e. "*Why horticulture land use systems are preferable for more C sequestration than other farming systems such as agriculture and agroforestry?*" However, there is a various vast array of hypothesis behind it but it is clear that perennial horticulture system having more potential of C sequestration that enhance nutrient sink capacity rather than other farming practices. Although, perennial fruits systems contain high biomass C which is 25–100 times higher than agricultural land use system. Hence, perennial horticultural systems are preferable and adopted to degraded and some others vacant land than agricultural crops and AFs. Undoubtedly agroforestry and horticultural systems reduced GHGs emission into the atmosphere and mitigate climate change issue by sequestrating more atmospheric C. But horticulture-based plantation system has proven more C sequestration potential than agroforestry and other farming practices. In this context, many authors have worked out and justify this hypothesis by some practical and research works. For example, a comparative study was conducted on C sink potential in between agroforestry land use system and horticultural land system for offsetting GHGs emissions (Bloomfield and Pearson 2000). By 2050, the potential of C sequestration will be more (16.4 GtC) as compared to 6.3 GtC through AFs in the tropics (Brown et al. 1996) whereas these sequestration value will be 3.5 GtC in horticulture systems as compared to 1.15 GtC in AFs by upcoming 2050 (Trexler and Haugen 1994).

Absorption and fixation of atmospheric C by woody perennials trees and fruits plants in agroforestry and HBFs are proven a better solution for mitigation climate change by reducing the level of GHGs in the atmosphere. However, sequestration of C in soils & vegetation plays an important role in maintaining soil health & quality in AFs & HBFs. Improvement of soil physico-chemical properties is a good indicator for soil health in AFs and HBFs which is itself a complex type of farming systems in which nutrient leaching is less as compared to sole based cropping system due to closed type of nutrient cycling and nutrient pumping is possible through deep rooting system of trees & fruit crops that adds more availability of essential nutrient to plants. Apart from the soil improvement, these systems add more biomass and C input, increase nutrient input, add more organic matter into the soil, efficient nutrient cycling, improve the rhizosphere zone, increase microbial population, minimize soil & water erosion, evaporation and nutrient leaching losses gets checked and overall improvement of micro-climate is observed. In this context, a model (Fig. 7.5) is developed which represents C sequestration and soil health in AFS and HBFS (Sarvade et al. 2019; Shi et al. 2018; de Stefano and Jacobson 2018).

Thus, AFs and HBFs have proven itself as a good strategy for soil, environment and food security. Woody perennial trees in both AFs and HBFs make availability of leaves, twigs and other residues and its decomposition add organic matter into the soils that improve productivity, fertility and nutrients uptake capacity of soils which in turn enhance the C sequestration potential of the systems that improve overall soil ecosystems. In turn, healthy soils having optimum nutrients and water availability and provide anchorage to various models of AFs and HBFs in the tropics that produce healthy, nutritious and good quality food, fruits and maintain FNS in the era of hunger and malnutrition problems. In this context, a model (Fig. 7.6) is developed on soil for sustainability of AFs and HBFs in the tropics (Dollinger and Jose 2018; Colmenares et al. 2020). However, farmers get motivated, take a lesson and adopted the better scientific oriented farming systems which help in building their health, income & livelihoods (Dollinger and Jose 2018; Colmenares et al. 2020).

Das et al. (2020) has reported the maximum value (1.63%) of SOM in livestock's and horticultural based farming systems as compared to 1.6% in AFs. This is due to

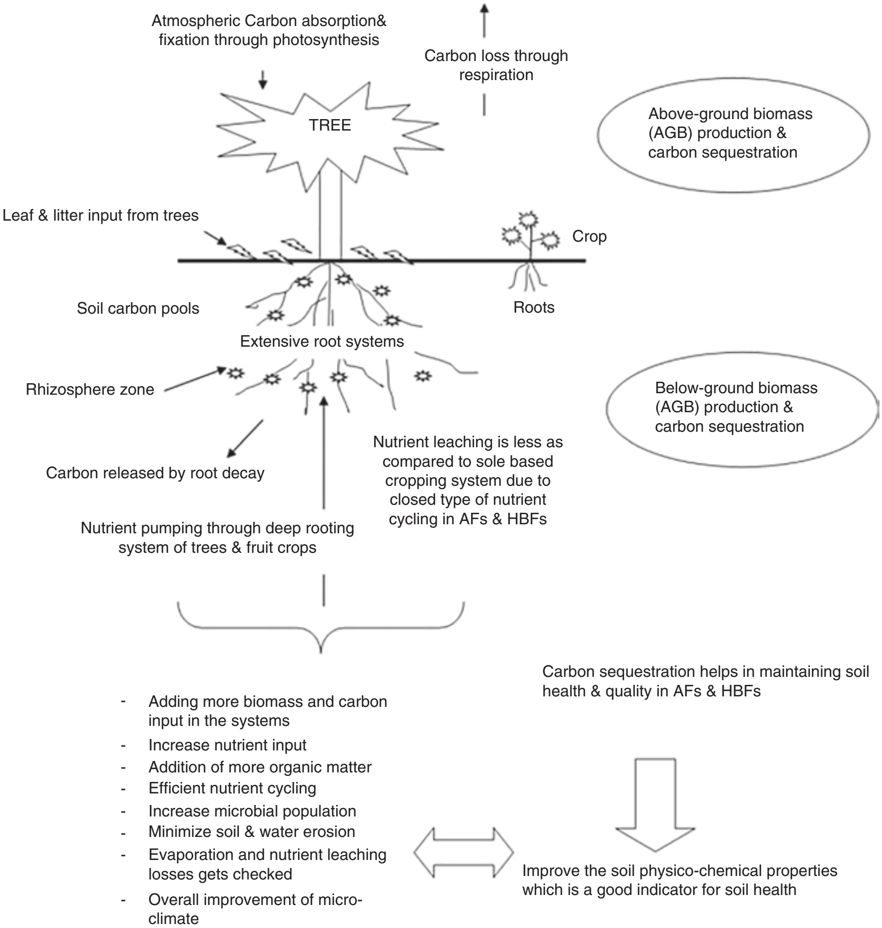

Fig. 7.5 Carbon sequestration and soil health in AFS & HBFS (Sarvade et al. 2019; Shi et al. 2018; de Stefano and Jacobson 2018)

ameliorating potential of acidic soils by minimizing Al-toxicity was more in livestock's and HBFs as compared to AFs. Das et al. (2020) also investigated on nutrient input and according to the study agri-hort-silvi-pastoral systems contributed highest input of exchangeable potassium (K) whereas maximum value of phosphorus (P) was observed in both agriculture and livestock's-based farming systems due to availability of cow dung and its continuous dressing over time. Therefore, agriculture system contributed more in total fertility build-up followed by agri-horti-silvi-pastoral and livestock's-based farming systems.

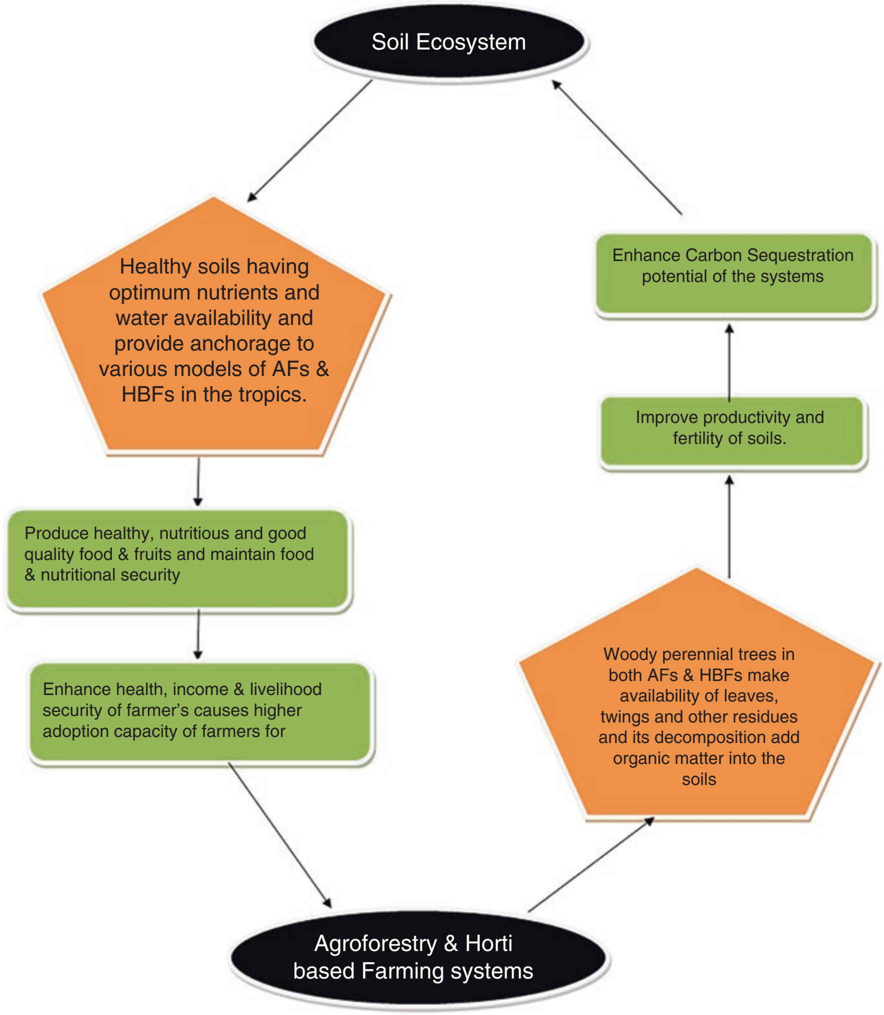

Fig. 7.6 Soil for sustainability of agroforestry and horticulture-based farming systems in the tropics (Dollinger and Jose 2018; Colmenares et al. 2020)

7.13 Carbon Sequestration and Rhizosphere Biology in AFS and HBFS

Today, the soil ecosystem is gaining high attention and is characterized by vast scientific frontiers in the rhizosphere make a remarkable position and active portion due to stabilizing a link between plant root and soil interface that involves effective biogeochemical processes and maintains ecosystem stability (Hiltner 1904; Hartmann et al. 2008). The major questions are "*How the rhizosphere system involve* *in feeding the world and maintains environmental/ecological sustainability*?" and "*How plant root system involves in C transfer from atmosphere to rhizosphere*?" As we know, rhizosphere exists in between plant root and soil interface that harbor all living microorganisms which makes nutrient availability and transfer. However, plant types, age and varying biotic and abiotic stresses affects rate of loss of C i.e. C transfer which is 40% of total photosynthate is lost through extensive root systems into rhizosphere system that promotes the bacterial multiplication for better growth and development inside this zone. In turn, a healthy microorganism promotes healthier plants through better uptake, storage, nutrient cycling, pathogen suppression and better soil structure. Therefore, rhizosphere promotes microbial productions which intends for healthier and diversified farming systems by healthier soil that leads to high biomass production, quality food and fruit productions along with better C sequestration potentials of systems. That's why we call "*better rhizosphere biology involves in food and environmental security through better C sequestration*". Thus, there is a great synergy between rhizosphere biology and soil-food-climate security.

7.14 Carbon Sequestration in Relation to Climate Change and Food Security

Carbon storage and sequestration play key role in biomass production (Raj and Jhariya 2021a, b) in term of timber, fiber, NTFPs including nutritive fruits which ensure food and nutrition security under changing climate. Agroforestry system performs unique functions in climate change adaptation and mitigation through C sequestration potential. Food productions in agroforestry system are linked with C storage in term of vegetation and soil biomass (Nair et al. 2009a, b; Niles et al. 2002). However, a climate resilient agroforestry and horticulture-based farming system enhance grains and fruits biomass which ensure food security and its sustainable utilizations among peoples. As per Lal and Bruce (1999), approx. 0.75–1.0 Pg yr^{-1} of C sequestration has been reported under global croplands ecosystem. Storing C in soil under agroforestry and horticulture-based system play key role in belowground biomass production which also maintain SOC pools. "Soils for food security and climate" are key initiatives of "4 per 1000" which was successfully launched in the year 2015. This initiative under The Paris Agreement has stressed on limiting global warming below 2 °C. This is targeted to enhance SOC sequestration with three objectives including climate change mitigation, adaptation and food security improvement for long term (Demenois et al. 2020). Similarly, integrating perennials crops (cacao and coffee) in agroforestry systems enhance C sinks than sole cropping system. Increasing perennial trees in farms under semi-arid regions promotes agroforestry systems and its C sequestration potential under changing climate (Brandt et al. 2018). Horticulture based mixed farming systems integrated various crops, fisheries and livestock enhance plant productivity along with climate change mitigation and adaptation (Newaj et al. 2016). This system also provides many nutritive food and fruits that ensure food security for healthy ecosystem. Similarly, this system is more diversified which buffer excessive temperature and enhance C sink and biomass production for healthy diets under changing climate (Bailey 2016; Waldron et al. 2017).

7.15 Agroforestry and Horticulture Role in Food and Nutritional Security Under Changing Climate

As per FAOSTAT (2018), 821, 151 and 613 million of people, including children, and women are undernourished, stunted and suffered from iron deficiency respectively. Whereas 2 billion people including adults are under obese and overweight. These are due to unhealthy, untimely and less nutritive food consumption. At the same time the current food production systems, especially intensive agriculture, contribute significantly to the environmental degradations. Beside the producing nutrient rich crops, the environmental footprint can be minimized by adopting agroforestry and horticulture-based farming system which ensures environmental health as well as global hunger problem under changing climate. In Kenya, women play important role in climate change mitigation by some innovative techniques of rainwater harvesting systems under varying agroforestry system which ensure food and water security by their collective efforts (Gabrielsson and Ramasar 2013). Thus, different agroforestry models and its adoptions provide various ecosystem services including food production and nutritional security through climate change mitigation (Sanz et al. 2017). Moreover, agroforestry systems improve biodiversity, food productivity, and ecosystem restoration under varying climatic situations (Paudela et al. 2017; Newaj et al. 2016). World Bank (2012) reported a global food production must be increased by 70% for upcoming 35 years due to higher demands of food production by 9 billion populations. However, it is still unclear to examine how climate change affects overall plant productivity and food security in agroforestry system. Global climate change decline agroforestry productivity and various ecosystem services particularly in developing countries. However, many developing countries are still facing food insecurity. In this context, adopting sustainable farming system including climate resilient agroforestry technologies and horticulture-based farming system would be helpful in soil-food-climate security for long term (Ospina 2016). However, forest-based farming system including afforestation activities also improves soil, food and environmental security along with other natural resource conservation (Raj et al. 2020a, b, 2022). Climate resilient agroforestry system ensures greater food diversification which provides healthier diet to people. Horticulture based farming system comprises different perennial fruits plants which is highly nutritive and regulate people health and economy. These integrated farming systems maintain soil-food and climate security along with ecosystem health and environmental sustainability.

7.16 Management Aspects for Improving Carbon Sequestration

As we know, unscientific and faulty land use practices disturb the global C cycle due to imbalance of emissions and sinks of C that affects the status of SOM and related ecosystem services (Jaiarree et al. 2014). A proper land use system always enhances the performance of varying farming systems in storage and sequestration of C along with multiple benefits through ecosystem services. Intensification in agriculture, perennial horticulture and AFs resulted higher synthetic inputs that leads to land degradation and minimizing C stocks in both vegetations and soils. In this context, applying ecological and sustainable intensification in these varying farming practices can intensify ecosystem services through enhancing biodiversity with higher production of food and fruits along with food-soil-climate security through better C sequestration potential (Jhariya et al. 2021a, b).

In nutshell, a better management practices in farming systems are needed for better rhizosphere biology, healthier microbial populations, better nutrient inputs and uptake by plants, soil health fertility improves that results greater potential of C sequestrations, maximize the availability of SOC which helps in maintaining healthier ecosystem performance (Fig. 7.7) (White III et al. 2017; Ahkami et al. 2017). Similarly, tree-crop interaction play major role in establishment and performance of multistoried perennial's horticulture based farming system and AFs in which management practices must be apply for better understanding of ecological and economic interactions between woody (timber and fruit trees) and non-woody components (annual crops, grasses and pastures, etc.). Therefore, varying components and their interactions provide a scope for number of scientific studies which explores the underlying ecological principles of these farming systems at temporal and spatial scale over the time. Soil management is an important aspect which regulates proper growth and productivity of agroforestry and horticulture systems comprising both annual and perennial crops. Whereas, C sink is possible through healthy soils and healthy soil is possible through better soil management practices. Thus, management must be focused in taking account of soil management which directly correlates with C sequestration that helps in healthy and quality productions in both AFs and HBFs. Conservation tillage, proper mulching, applying cover crops, maintaining soil fertility, nutrient availability, enhancing nutrient use efficiency, water management through better irrigation system, technology for controlling soil and water erosion, etc. are many options that must be follow for better soil C sequestration.

7.17 Critical Research Needs for Enhancing Carbon Sequestration in AFS & HBFS

An ample of research has already been conducted that explore the complex nature of horticulture-based farming and AFs having multiple array of significance in term of varying ecosystem services but some parts of research remain unaddressed. For

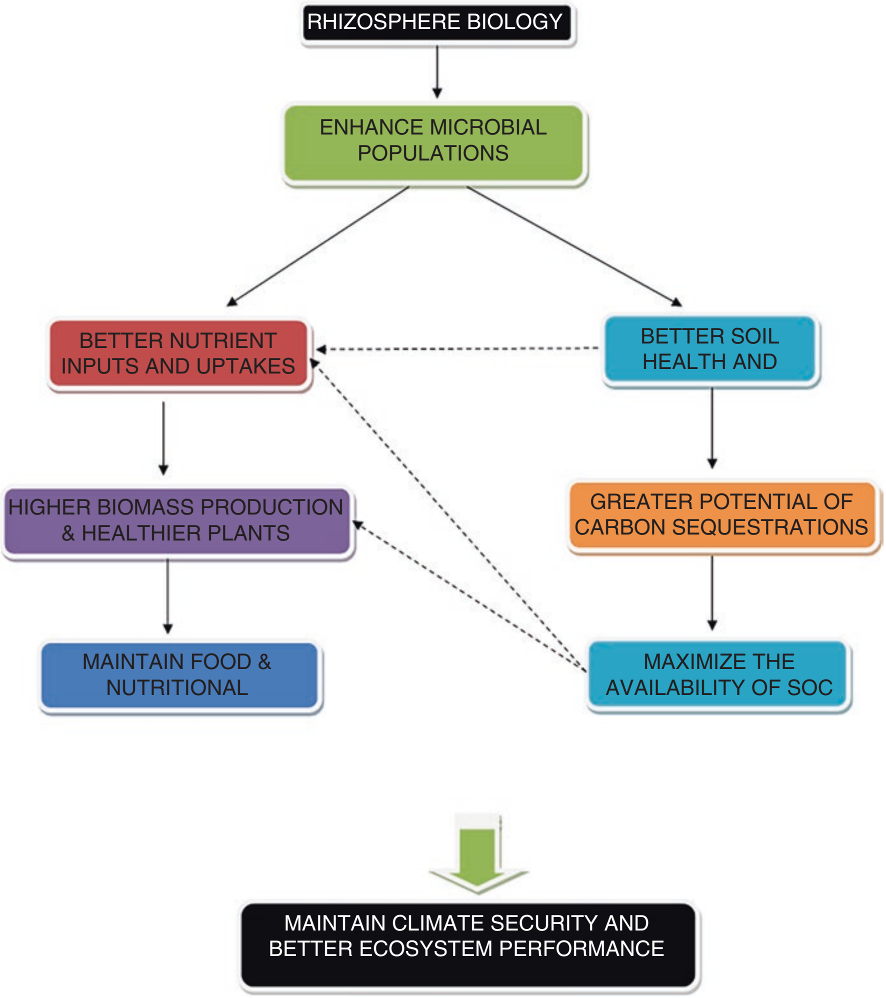

Fig. 7.7 Rhizosphere biology for better ecosystem performance (White III et al. 2017; Ahkami et al. 2017)

example, research is needed to understand the underlying truth of tree-crop-animals-soil interactions and related productivity, profitability and in accordance of political and social milieu in agroclimatic zones. Similarly, research should be undertaken for development of degraded, waste and salt affected areas through AFs and perennial HBFs in agroclimatic zones of India. Further, a detailed study on C sequestration potential of different woody perennial trees comprising timber and fruit tree are needed. However, many authors have reported the potential C sink value of different trees used in urban forestry, agroforestry, HBFs and other land used practices in the tropics which are depicted in Table 7.8. As per Forrester et al. (2006) some indigenous tree species like neem (*Azadirachta indica*), Mahua (*Madhuca latifolia*),

Table 7.8 Carbon sink value in different tree species

Different tree species	Carbon sink value reported by authors	Reference
Australian wattle (*Acacia auriculiformis*)	7.7 Mt C/year	Raizada et al. (2003)
North Indian rosewood (*Dalbergia sissoo*)	3.6 Mt C/year	
Coast she oak (*Casuarina equisetifolia*)	1.9 Mt C/year	
Gamhar (*Gmelina arborea*)	1.4 Mt C/year	
California redwood (*Sequoia sempervirens*)	5000 t C/ha	Runyon et al. (1994)
Douglas-fir (*Pseudotsuga menziesii*)	1000 t C/ha	
Deodar (*Cedrus deodara*)	469.1 t C/ha	Sharma et al. (2011)
Bahera (*Terminalia bellirica*)	327.78 t C/ha	Hangarge (2012)
Eucalyptus spp.	320.67 t C/ha	Chavan and Rasal (2011)
Black wattle (*Acacia mangium* Willd.)	292.02 t C/ha	Ilyas (2013)
Tropical clumping bamboo (*Bambusa balcooa*)	234.17 t C/ha	Borah and Chandra (2010)
Indian Bat tree (*Ficus amplissima*)	221 t C/ha	Hangarge (2012)
Teak (*Tectona grandis*)	181 t C/ha	Sreejesh et al. (2013)
Rubber tree (*Hevea brasiliensis*)	136 t C/ha	Dey (2005)
Poplar (*Populus deltoids*)	115 t C/ha	Gera et al. (2006)
Mango (*Mangifera indica*)	104.41 t C/ha	Chavan and Rasal (2012)
Ban oak (*Quercus leucotrichophora*)	77.3 t C/ha	Sharma et al. (2011)
Siris tree (*Albizia lebbeck*)	11.97 t C/ha	Jana et al. (2009)
Sal (*Shorea robusta*)	8.97 t C/ha	
Ten years orchard of Mango (*Mangifera indica*)	58.1 kg tree^{-1} by	Shinde et al. (2015)
Fifteen years orchard of Mango (*Mangifera indica*)	115.4 kg tree^{-1}	
Ten years orchard of Coconut (*Cocos nucifera*)	56.6 kg tree^{-1}	
Fifteen years orchard of Coconut (*Cocos nucifera*)	126.3 kg tree^{-1}	
Ten years orchard of Jamun (*Syzygium cumini*)	38.7 kg tree^{-1}	
Fifteen years orchard of Jamun (*Syzygium cumini*)	78.8 kg tree^{-1}	
Ten years orchard of Guava (*Psidium guajava*)	32.9 kg tree^{-1}	
Fifteen years orchard of Guava (*Psidium guajava*)	54.3 kg tree^{-1}	
Mango tree orchards of Indian subcontinent	285.0 MT C	Ganeshamurthy et al. (2019)

peepal (*Ficus religiosa*) and tamarind (*Tamarindus indica*), etc. have high potential to sequester more C and fix into them as biomass which also helps in minimizing the pollution in urban and rural areas. Moreover, a critical research is needed to understand the soil genesis and its pedology for better soil health management which is directly link with rhizosphere biology, microbial population, C sequestration potential, extent of SOC, nutrient use efficiency, quality food and nutritious fruits productions and other varying ecosystem services for better environment and ecological stability.

Thus, research should be undertaken in accordance of maximizing potential of C sequestration in both vegetation and soils in agroforestry and horticulture land use systems which can be possible through understanding the interaction magnitude among tillage practices, varying climatic situations and soil types on C sequestration. Also, topics such as (a) exploration the C sequestration potential of various agroforestry and perennial horticulture system in agroclimatic zones, (b) evaluation the synergy between C and soil-crops health & productivity, (c) evaluating the practices of C sequestration for GHGs emissions, (d) horticultural waste based biochar production and its role in C balance and SOC in soils, (e) quantifying the impact of tree pruning for better light penetrations and photosynthesis in varying fruits orchard along with its significant role in retaining soil C through conversion of tree pruned biomass into biochar and its application into the soil and (f) evaluating the significance of conservation practices in both AFs and HBFs beyond the C sequestrations etc. should be addressed.

7.18 Policy and Legal Framework

As we know, C sequestration is win-a-win strategy to combat global warming and other negative consequences of climate change which already popularized by various government, NGO, national and international organizations and policy maker in the world. Policy must be in frame of conducting more research on C sequestration potential of varying land use farming systems in priority basis. Governance and policy should develop a legal framework on exploration and understanding of C sequestration and SOC pools through better soil management practices in horticulture and AFs in varying agroclimatic zones. Policy should be aimed towards regulating C balance and enhancing C sink into both vegetation and soils to offset GHGs emissions by every practical aspect which would be helpful in maintaining tree-crop-soil health, productivity and climate security for ecological sustainability in long term basis.

7.19 Conclusion

Today, emissions of GHGs are major challenges and it can be minimized by practices of better horticulture and AFs that not only mitigate the issue of climate change but also helps in maintaining C balance in environment, enhance SOC and nutrients input into the systems, promotes microbial population through better rhizosphere technology, intensify the ecosystem services through enhancing biodiversity, resource use-efficiency, maximize productivity i.e., quality food and fruits that helps in maintaining food-nutrition-climate security. It is now crystal-clear hypothesis and assumption regarding better performance of perennial horticultural systems in C sequestration than other farming practices like agroforestry and annual cropping systems. Also, perennial horticultural land use systems deliver better economic return through C credits. Soil stores much C pools for long time by better soil management practices, healthy rhizosphere biology, less synthetic inputs under eco-intensification practices that all intensify the ecosystem services and whole ecosystem sustainability. Thus, better management of soil and whole farming systems are important for better consequences of C sequestration in term of biomass productions and others uncountable tangible and intangible benefits through ecosystem services which maintains ecological sustainability.

7.20 Future Thrust

The C dynamic, its source and sink are the key criteria for planning C reduction, emission, financing and trading. The AFs, HBFs and other agroecosystems related land-use are the key concern in terms of food security, climate change and C emission-reduction processes. In this connection proper monitoring, modelling and assessment are needed time to time with upgradation of technology in different land-use to strengthening the knowledge regarding the trends of C emission-reduction. Similarly, the limited studies are available on C sequestration potential of diverse fruit and vegetable-based horticulture land use systems in different agro-climatic zones in India. Surely, it will give a new dimension to study and emphasis should be given on to identify a suitable species and develop a suitable propagation protocols along with better management practices which would help in enhancing C sequestration and productivity of varying perennial fruits and vegetables. Thus, more studies are needed to quantify C sequestration potential and various types of footprints in different land system. Further, various models were properly tested in different agro-climate zone along with varying site conditions for incorporation and promotion of C enrich technology in different plantation activities and government schemes. The potential of C sequestration by various indigenous species and the species having wider ecological amplitude were screened out for achieving the higher C sink and to move forwards with sustainable approach.

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Chapter 8
Pesticide Residue and Food Safety: Retrospection and Prospects

Sunil Aryal and Lok Nath Aryal

8.1 Introduction

Chemical pesticides have been one of the key means and will be the major one in the future as well to protect crops from pests. Various pesticides were used as insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, etc. Furthermore, pesticides are classified as biopesticides, biochemical pesticides, chemical pesticides, organic and inorganic pesticides based on their targets, action mechanism, chemical properties, etc. (Leong et al. 2020). Pesticides use in agricultural production systems have been increasingly practiced these days to minimize crop losses whose ultimate goal is to feed the growing population worldwide. Food production needs to feed 9.73 billion people until 2050 for which it is expected to increase agricultural product demand by 50% (FAO 2017). Therefore, realizing the need to grow more in the future, along with improvement in various inputs of agriculture, an increase in the use of pesticides in the future seems inevitable. Since the formulation of the DDT by Paul Muller (Anonymous 1965), the continuous use of chemical pesticides in the agriculture and the health sector has impacted in both positive and negative ways. Positive impact is reduced crop loss due to pests which increase food in terms of quality and quantity (Damalas 2009). The use of different pesticides in vector control has also reduced the transmission of vector-borne diseases to humans (WHO 2019). For example, 42% reduction in mortality due to malaria was observed in 2000 due to the control of vectors (https://croplife.org/wp-content/uploads/pdf_files/Vector-Control-fact-sheet.pdf) by an integrated approach including pesticide use (WHO 2017). Not only in agricultural pest and vector control, but an increase in pesticides has also contributed to overall economic development (Hedlund et al. 2020). Though pesticide has an immense positive

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contribution to humankind it has a negative impact as well (Damalas 2009). Since pesticides are toxic, their effect on human and livestock health is always at risk if guidelines for pesticide handling are not properly maintained. There is another problem associated with the frequent use of the pesticide where resistance to create pests switching to alternate pesticides. Resurgence and outbreaks of pests are the major problems, while vulnerable natural enemies die due to the toxic effect of chemical pesticides. Residue problem from the use of DDT was realized as early and was discouraged to use in forage crops (Decker 1946). Pesticide contamination could pollute the air, water, and soil (Tudi et al. 2021) as well as it has some negative effects on the whole ecosystem (Sharma et al. 2019; Pisa et al. 2021) where the accumulation of persistent pesticides as residue could occur. Bio-magnification and bioaccumulation of persistent pesticides is another problem that increases the risk to the organism. There are large differences in implementing and executing international rules and regulations related to pesticide management due to the lack of proper knowledge, funding, infrastructure as well as skilled manpower in developing or low-income countries than developed countries. Therefore, this chapter aims to look at the pesticide residue problem in retrospection and prospects for mitigation giving emphasis to developing countries.

8.2 Pesticide Consumption

Total pesticide (active ingredients, a.i.) use in the world has increased from 1.7 million tons in 1990 to 2.7 million tons in 2020 (FAOSTAT 2022) (Fig. 8.1a). Total pesticide consumption in Nepal has also increased from 60 to 681.5 tons. Though the total pesticide used for agriculture in 2020 was only 681.5 tons (Fig. 8.1b), the increase in pesticide use in Nepal when compared to 1990 was very high (91.2%) among the countries.

FAOSTAT (2022) showed that the USA used the maximum amount (407779.5 tons) of pesticides in 2020 followed by China (273375.5 tons), Brazil (231621.2 tons), Argentina (132255.1 tons), and France (81463.79 tons) (Fig. 8.2a). The top

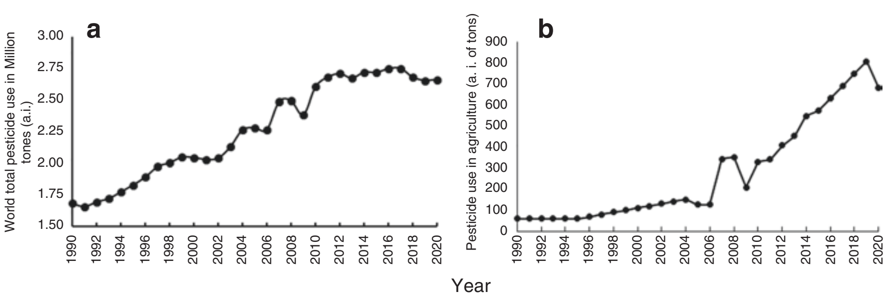

Fig. 8.1 Rise in total pesticide use in Agriculture (**a**) World, (**b**) Nepal from 1990 to 2020 (FAOSTAT 2022)

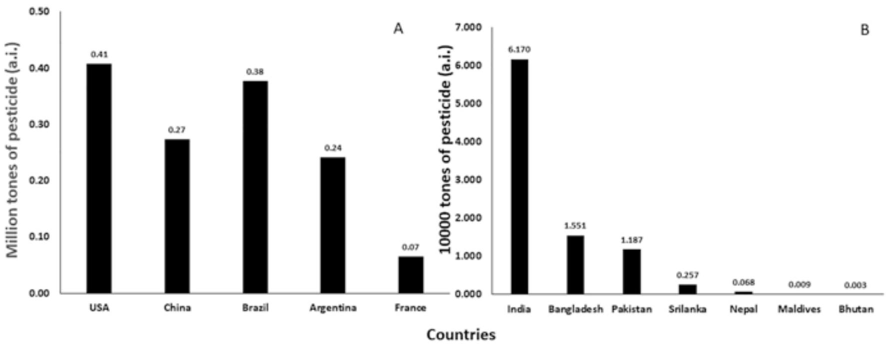

Fig. 8.2 (**a**) Top 5 countries that uses maximum amount of total pesticide in agriculture during 2020. (**b**) Total pesticide use in agriculture by South Asian (SAARC) countries during 2020

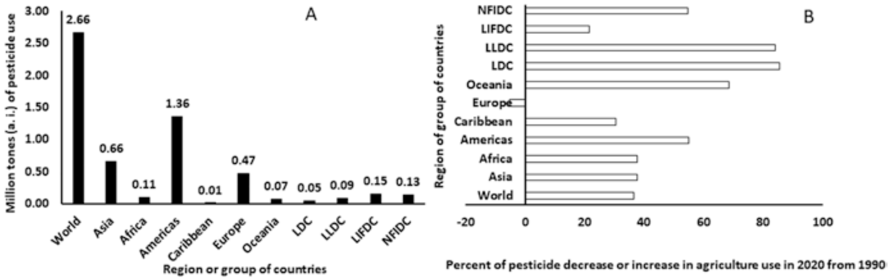

Fig. 8.3 (**a**) Total pesticide used in agriculture by different region or countries during 2020. (**b**) Percent increase or decrease of pesticides use in agriculture by region or group of countries during 2020 compared to 1990. LDC Least Developed Countries, LLDC Land Locked Developing Countries, LIFDC Low Income Food Deficit Countries, NFIDC Net Food Importing Developing Countries

total pesticide user in South Asia is India (61701.9 tons) followed by Bangladesh (15506.47) in 2020 (Fig. 8.2b).

Pesticide consumption for agricultural use has been in increasing trend in many countries. The concern is that most of the pesticide (89%) was only used in vegetables (PRMS 2015) 1.45 to 1.6 kg a.i./ha (Sharma 1994; Thapa 1997, PRMS 2015). Similarly, the pesticide used in agriculture increased rapidly as compared to the world total with the regions and group of developing countries. When compared to the world total Americas (1.36 million tons) used most pesticides in agriculture followed by Asia and Europe while group of developing countries have less pesticide use in agriculture (Fig. 8.3a). Though the group least developed and developing countries have far less use of pesticide in agriculture, the problem of pesticide residue there persist because of improper handling of pesticides and lack of regular advance monitoring and residue analysis systems (GC and Palikhe 2021). When total pesticide used in agriculture during 2020 is compared with use in 1990, all the regions across the world have increased use of pesticide while use of pesticide amount has been shown decreased by 5.2% for European countries. Least Developed Countries (LDC), Land Locked Developing Countries (LLDC), Low Income Food Deficit Countries (LIFDC), Net Food Importing Developing Countries (NFIDC) have increased pesticide use in agriculture; LLDC and LDC being countries with high increase of pesticide use (Fig. 8.3b). These statistics clearly showed that the countries with low income and food deficit group need assistance in many aspects of pesticide use and monitoring.

Though pesticide use was very less in low-income countries, there is a clear gap in knowing the pesticide efficacy and its ill effects on human health and the environment in various stages of the pesticide cycle like policy formation and implementation, pesticide application, implementation of IPM, etc. (van den Berg et al. 2020). Awareness regarding various aspects of pesticide use like proper pesticide handling, proper doses, and frequency, safety measure while application, proper disposal, selection of proper pesticides for targeted pests especially in low-income countries are very limited and the problem is very prominent (Maharjan et al. 2004; Giri et al. 2004, 2014; Aryal et al. 2020; Staudacher et al. 2020; Negatu et al. 2021). The lack of adequate adoption of IPM also causes pesticide-related problems. Low adoption of the IPM may be due to low funding, insufficient knowledge and inputs, policies, user preferences, and lack of practical technologies, especially in low-income and developing countries (Tiwari et al. 2020; Day et al. 2022). Problem of pesticide residue arises when there is improper use and management of pesticides while contaminated shipment from abroad also causes health risks to the consumers. During 2018, countries that used maximum amount of pesticides per unit of cropland were Mauritius (28 kg/ha), Ecuador (26 kg/ha), Trinidad and Tobago (25 kg/ha), Costa Rica (22 kg/ha), Bahamas (21 kg/ha), Barbados (21 kg/ha), Saint Lucia (20 kg/ha), China (13 kg/ha), Israel (13 kg/ha), and Seychelles (12 kg/ha) whereas in 2020 top 10 countries are different than in 2018 which were Saint Lucia (20 kg/ha), Maldives (17 kg/ha), Oman (16 kg/ha), Israel (15 kg/ha), Ecuador (14 kg/ha), Seychelles (12 kg/ha), Japan (12 kg/ha), Belize (11 kg/ha), the Netherlands (11 kg/ha) and the Republic of Korea (10 kg/ha) (Table 8.1).

8.3 Problems and Effects of Pesticide Residues

After the formulation of dichlorodiphenyltrichloroethane (DDT) by Paul Muller in 1939, its use was widespread in vector and agriculture pest control (Anonymous 1965). But residue of DDT was detected as early as 1946 and was discouraged to use in forage crops (Decker 1946). Since then, effects and problem arose by pesticide residue has been experimentally proved or reviewed by various researchers around the globe.

Table 8.1 Top ten countries for pesticide use per unit of cropland during 2018 and 2020

SN	Countries	2018[a] (kg/ha)	2020 (kg/ha)[b]
1	Mauritius	28	–
2	Ecuador	26	14 (5)
3	Trinidad and Tobago	25	–
4	Costa Rica	22	–
5	Bahamas	21	–
6	Barbados	21	–
7	Saint Lucia	20	20 (1)
8	China	13	–
9	Israel	13	15 (4)
10	Seychelles	12	12 (5)
11	Maldives	–	17 (2)
12	Oman	–	16 (3)
13	Japan	–	12 (7)
14	Belize	–	11 (8)
15	The Netherlands	–	11 (9)
16	The Republic of Korea	–	10 (10)

Source: FAO (2018, 2020)
[a]Data in third column are for top 10 countries in ranked order as listed in column 2
[b]Data in fourth column are representing the top 10 countries without ranked order. Ranking is given in parenthesis

8.3.1 *Effect on Non-target Animals*

Out of the total pesticide use, 80% of the pesticide directly affects non-target animals (Sajjad Ali et al. 2021) which can also contaminate ecosystems of soil and water (Aktar et al. 2009; Giri et al. 2016). Active ingredient of the pesticide can also affect non-target animals in agro-ecosystems like vertebrate and invertebrate predators and parasitoids. Contact toxicity of some pesticide residue has already been tested as early in 1963 where most of the tested pesticides cause high to medium toxicity on hymenopterous parasites (Bartlett 1963). Barros et al. (2018) showed that the residue of chlorantraniliprole, chlorfenapyr, spinosad, lambda-cyhalothrinn, methidthion, pymetrozine and thiamethoxam caused mortality to parasitoids in cotton ecosystem. Similarly, Pesticide residue increases in plant and animal through the phenomenon called bioaccumulation and bio-magnification (Bro-Rasmussen 1996; Carvalho 2017; Chormare and Kumar 2022). Honey bee decline is also responsible due to the use of organophosphate, pyrethroid, systemic neonicotinoids, imidacloprid and thiamethoxam in agriculture (Ali et al. 2021).

8.3.2 Bioaccumulation and Bio-magnification

Pesticide uptake from contaminated food and water inside the body of an organism is referred to as bioaccumulation whereas the increased accumulation of the pesticide residue in organisms as increased in trophic level is the ecological magnification (Gupta and Gupta 2020). Chemical pesticides applied to agricultural crops may be deposited in soil, washed by runoff, and could contaminate rivers and ponds. This process of contamination of water bodies was presented by Kale et al. (1999) who found that Metabolized DDE bio-accumulated in the aquatic food chain and ultimately was transferred to humans. Most vulnerable to be affected by these two phenomena are the members present at higher trophic levels i.e. humans where bioaccumulation could occur when uptake of marine and agricultural diet, while contaminant enters through respiration has less likely to get accumulated (Czub and Mclachlan 2004). Rossi et al. (2020) tested the pesticide in fish inhabiting rice fields before and after the application of the pesticide where he found that all the specimens of *M. nigripinnis* had tested pesticide accumulated inside it after 21 days of applications in considerable amount. Fish reared in rice fields have increased levels of lambda-cyhalothrin and tebuconazole accumulated in muscles (Clasen et al. 2018) which have inflicted significant adverse effects on fish itself as well as possess a risk to humans who consume pesticide bioaccumulated fish. Similarly, tigerfish (*Hydrocynus vittatus*) from the Luvuvhu river had a high level of accumulation of organochlorine pesticides which even exceed the maximum residue level set by the European Union (Gerber et al. 2016) which even poses a high risk of cancer to the populations who consume contaminated fish around the area. Bonansea et al. (2016) exposed fish *Jenynsia multidentata* to cypermethrin and chlorpyrifos individually and in combination where they found that cypermethrin and chlorpyrifos accumulation is measured higher in the liver followed by the intestine, gills, and muscles in the mixture than exposed with single pesticide. Panseri et al. (2019) studied the persistent organic pesticide accumulation in Tuna, Sea bream, and Dentex fishes where they found high OC accumulation occurred in tuna fish. Organochlorine residue accumulation of some fish species from East Kolkata also reveals contamination of DDT, endosulfan, and dicofol in three fish species. Moreover, Pérez-Parada et al. (2018) reviewed and discussed the pesticide bioaccumulation on freshwater fish which ultimately concerns human food safety. Biomagnification in the aquatic ecosystem was assessed by Tongo et al. (2022) at Ikpoba River of Nigeria where they showed transfer of the pesticide in trophic levels where Food Chain Bio-magnification value for certain organochlorines, glyphosate, carbofuran, and diazinon were high.

Bio-magnification in the terrestrial food chain is much higher than that of aquatic food chain (Gobas et al. 2013). Terrestrial ecosystem contamination was basically from the aquatic sources of pesticides which could be due to biologically mediated pathways like terrestrial food webs or abiotic pathways from runoff, flooding, and groundwater contamination (Schulz and Bundschuh 2020). Terrestrial organisms around the pesticide factory were also not pardoned due to the pesticide residue problem. Though the highest level of residues of organochlorine was found in soil around the factory, the concentrations of residues in insects, chickens, and birds were moderate and are within the acceptable safe limits (Tang et al. 2016). Wild life terrestrial populations have higher levels of POPs pesticides, and are at a higher level of trophic levels (De Solla 2016). Trophic magnification factors in the terrestrial food web were between 1.2 and 15 for POPs pesticide which indicated that it has a greater capacity to get magnified (Fremlin et al. 2020). Transfer process and bio-magnification of pesticides in the terrestrial ecosystems from soil to vegetation and animal was well described by Connell (2018). Not only the pesticide cause problems in the application area but can also inflict a problem in the neighboring area or even neighboring countries. Yadav et al. (2015) reviewed that the POPs in the air, water, and soil can possibly affect neighboring countries.

8.3.3 Pesticide Residue in Agriculture Products and Food

Residues on fruits and vegetables coming to the Nordic countries from South East Asian countries have been studied where pesticides were detected in 111 samples out of 721. 14% of the sample contained residue more than MRL of EU standard some of which could cause an acute health risk for consumers (Skretteberg et al. 2015). EU-coordinated control program has collected 88,141 food samples and analyzed the residue level across the EU member states on 2020 which showed 94.9% of samples fell below MRL where 5.1% exceeded the level and 3.6% were non-compliant (EFSA et al. 2022). The samples which were non-complaint were increased by 1.3% than 2019 where non-compliant samples were about 2.3% (EFSA et al. 2022). Non-compliant subjected to legal sanctions or enforcement action.

Research in Bangladesh showed that 50% of green bean sample was contaminated with insecticide above EU MRL which poses threats to adult and children's health where an estimated daily intake of 2.79×10^{-4} to 2.96×10^{-4} in an adult with a hazard quotient of 0.56–0.59 and 9.79×10^{-4} to 1.77×10^{-3} with hazard quotient of 1.96–3.55 in children were reported. Children are more vulnerable to pesticide residue exposure (Parven et al. 2021). Carbendazim and chlorpyrifos residues were detected in eggplant, chilli and tomato samples in the Nepalese vegetable market (Bhandari et al. 2019) where pesticide residues in 4% of the eggplant, 44% of the tomato, and 19% of the chilli samples exceeded the EU MRLs. Further they also performed a risk analysis of human health where the highest acute hazard quotient (aHQ) was for triazophos (tomato) in adolescents (aHQ = 657) and adults (aHQ = 677), showing the highest risks of dietary exposure. There are some studies on pesticide residue by Nepal Agricultural Research Council and other organizations in Nepal which were comprehensively reviewed by Aryal et al. (2020) and Giri et al. (2016). When analyzing the consumption data, the group of least developed and developing countries have shown far less use of pesticide in agriculture, the problem of pesticide residue still persists because of improper handling of pesticides and lack of regular advanced monitoring and residue analysis systems.

Neonicotinoid residue has been extensively studied these days due to its toxicological effects in mammals and honey bees. One of the studies in US showed that, of the collected samples, all the vegetable samples except nectarine and tomato, and 90% of honey samples were detected positive for at least one neonicotinoid residues (Chen et al. 2014). A review paper from Pakistan reflects that 50% of samples were contaminated either with organophosphate or pyrethroids or organochlorine pesticides where 50% of the samples were having residues above maximum residue limits (Syed et al. 2014). Another review paper revealed that milk and milk samples collected from different parts of Pakistan contaminated with organophosphates and organochlorine pesticides (Akhtar and Ahad 2017). Pesticide residue in animal feed may cause problems in dairy animals which ultimately results in the loss of meat production (Choudhary et al. 2018). Not only pesticide residue related to own products but imported produce also need to be monitored and scrutinized to protect the health of the consumers.

8.3.4 Pesticide Residue Problem in Trade

There are many instances that the agricultural produce acceptance has been denied by importing countries because of non-compliance with food safety and health standards set by importing countries (Goyal et al. 2017). Most of vegetable shipment into the United States was refused because of pesticide residue problems (Buzby et al. 2008; Bovay 2016). China's refusal of food imports due to violations in complying with standards or excessive set values for some additives and chemicals including pesticides accounted for 27% of the total refusal from 2013 to 2019 (Gale 2021). Being more interdependency is prevailing among countries, the demand is for integration and harmony on rules and regulations on international trade (Whitehead 2019) but there is still asynchrony in the agricultural food trade due to asynchronous MRLs set by different countries which ultimately create trade problems worldwide (Yeung et al. 2017). Further, the differences in MRLs standards were described by Racke (2007) who compared the standard of MRL set by Codex, EU, Japan, and the US for some pesticides. There is a great threat in the trade of agricultural food products due to a lack of harmonization in pesticide regulation including different MRLs of different countries (Yeung et al. 2017). There are some differences in national or regional MRLs than that of Codex (Table 8.2). Some countries specified MRL for individual pesticides for a particular commodity or group of commodities.

Revision and changes in regulation (MRL setting) making them stringent could cause an exporting country hard to comply in time, and could be a great setback for them. Such example has been reviewed by Yeung et al. (2017) for revision of MRL for banana which causes difficulties for the Philippines to export them. Ghana cocoa exporters need seeking alternate market after stringent MRL value was set by Japan. Canada exporter could not meet the standard after EU asked to reduce MRL of

Table 8.2 Example of the MRLs comparison set by a different group of countries or specific countries for some commonly used pesticides for tomato (mg/kg or ppm)

	Pesticides	Codex	EU	US	S. Korea	India	Nepal
1	Chlorpyrifos	NA	0.01	NA	NA	NA	NA
2	Abamectin	0.05	0.09	0.07	0.05	NA	0.05
3	Spiromesifen	0.7	1	0.45	1	0.7	NA
4	Imidacloprid	0.5	0.3	NA	1	1	0.5
5	Malathion	0.5	0.02	8	NA	NA	0.5
6	Chlorantraniliprole	NA	0.6	NA	1	0.6	NA
7	Spinosad	0.3	0.7	0.4	1	NA	0.3
8	Cypermethrin	0.2	0.5	0.2	0.15	NA	0.2
9	Metalaxyl	0.5	0.3	1	0.5	NA	0.5
10	Tebuconazole	0.7	0.9	1.3	1	2	0.7

Sources:
https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/pesticides/en/
https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/mrls/?event=download.MRL
https://www.fas.usda.gov/maximum-residue-limits-mrl-database
https://www.foodsafetykorea.go.kr/foodcode/02_01_02.jsp?s_option=EN&s_type=12
https://www.fssai.gov.in/upload/uploadfiles/files/Compendium_Contaminants_Regulations_20_08_2020.pdf
http://www.dftqc.gov.np/noticedetail/80/2021/45518958
NA Not Available

chlorothalonil from 2 to 0.01 ppm. A total of 33,911 samples were analyzed for pesticide residues that were imported into the UK from 2000 to 2020 where 50.2% samples contained of detectable residue with 3.3% of samples having residue beyond MRLs (Mert et al. 2022). Food that exceeds MRLs is due to the amendments in food monitoring programs of the UK with strict provisions. Likewise, Stringent MRLs of European countries hinder the exports of fruits and vegetables by the US by 13.8% whereas worldwide bilateral trade is reduced by 8.8% due to stringent MRLs policy (Hejazi et al. 2022). Even developed countries like the US have found difficulties meeting the stringent standard set by importing countries, developing and underdeveloped countries are far less able to meet those standards. Ferro et al. (2015) clearly presented that exporters from low-income countries are having difficulties in exporting goods and are restricted to export due to stricter standards set by importing countries. Wilson and Otsuki (2004) showed that an increase of 1% in stringent regulation and tighter restrictions on chlorpyrifos resulted in a decrease in banana imports by 1.63%. They also simulate the gravity model to establish a difference in trade flow when regulatory standards are changed which directly affect the developing countries that export banana to OECD countries. They further analyze the loss of US$ 5.5 billion of exports occurs per year due to stringent standards set by the EU in contrast to a world standard i.e. Codex standards.

8.3.5 Human Health Risks Associated with Pesticide Exposure

Pesticide residues in food and their impact on human health were reviewed as early during the sixties when Durham (1963) explained its neurotoxicity and carcinogenic effects. POPS are known to have many adverse effects on human health such as diabetes, thyroid problems, endocrine disruption, behavioral problem, and even cancer (Islam et al. 2018). Pesticide residues can pose a concern to human health which may have short as well as long-term effects. Short-term effects may be headache, nausea, stomach pain, blurred vision, dizziness, vomiting, sweating, skin itching, etc. (Maharjan et al. 2004; Gerage et al. 2017) whereas long-term exposures could cause carcinogenic effects, Neurological effects, Endocrine disruptions, effect on reproduction and fertility (Debnath and Khan 2017; Ali et al. 2021) as well as the cause of mutagenic abnormalities are also associated with pesticides (Giri et al. 2002). Pesticide is responsible for causing cancer and was reviewed by Weichenthal et al. (2010) who revealed that lung, pancreas, colon, rectum, leukemia, multiple myeloma, bladder, prostate, brain, melanoma, lymphoma cancer was associated with at least one kind of different group of pesticides.

Acetylcholinesterase (AChE) enzyme activity was assessed using the modified Ellman method by Serrano-Medina et al. (2019) where they found anxiety was associated with 23.9% of farmers who have inhibited enzymatic activity whereas 23.5% showed effects of both depression and anxiety. Chronic exposure to organophosphate pesticides associated with neurological disorder includes anxiety, reduced motor conduction velocity, reduced serum AChE, reduced verbal memory, reduced motor speed, and motor coordination, and delayed polyneuropathy (Kori et al. 2018; Silver and Meeker 2020). Similarly, Kori et al. (2018) also pointed out the disorder associated with organochlorine, pyrethroids, and carbamates are neurochemical and behavioral disorders. Prenatal and early childhood exposure to organophosphate pesticide among children results in cognitive deficits in prenatal stage, behavioral deficits in toddlers and motor deficits in the children at age 7 (Muñoz-Quezada et al. 2013). Silver and Meeker (2020) also concluded that prenatal exposure of organophophates impact neurodevelopment, organochlorine may cause obesity, POPs may be associated with premature birth and it badly affects fetal growth, congenital abnormalities and childhood cancer (leukemia and brain tumors).

To overcome the problem associated with pesticide residue, there are several rules and regulations set worldwide and by individual countries, international convention on pesticide management, various activities proposed by countries to reduce the use of highly hazardous chemical pesticides. Those mitigation processes are discussed.

8.4 Techniques in Pesticide Residue Analysis

According to chemical properties and for level of detection different methods are employed for residue extraction and end analysis. Sample pre-treatment and extraction method may also vary depending upon which pesticide being analyzed. Various extraction methods are used since the residue analysis technique has been in practice. Liquid-liquid and solid-liquid extraction was common for residue extraction earlier (Narenderan et al. 2020) but now QuEChERS methods (Anastassiades et al. 2003) are used in most of the extraction which were further enhanced with various modifications. This QuEChERS method utilizes minimum quantity of solvent and reagents than earlier method of residue extraction. Likewise, chromatography was also got evolved from TLC to much sophisticated equipment's like GLC, GC coupled with detectors, GC/MS, GC/MS/MS, HPLC, LC/MS, LC/MS/MS, TQ UHPLC-MS/MS, UHPLC-IMS-QTOF MS and Surface enhanced Raman spectroscopy (Martins et al. 2017; Sarath Chandran et al. 2019; Narenderan et al. 2020; Lacalle-Bergeron et al. 2020; Soltani Nazarloo et al. 2021; Wahab et al. 2022). Further, reflective spectroscopy (VIS/NIR) can be used to detect pesticide without destruction of sample (Yu et al. 2020; Narenderan et al. 2020).

A rapid bioassay of pesticide residues (RBPR) has been introduced by TARI and has been adopted by many countries for quick detection of certain group of pesticide which involve acetylecholinesterase (Kao et al. 2010; Aryal et al. 2020). Recent year ELISA technique which employ antibodies or enzymes for different 18 pesticides have been developed which can detect pesticide residue ranging from 0.01 to 2.24 ppb (Chang et al. 2018). Some improvement and modification to enzyme-linked immunosorbent assay (ELISA) to enhance the sensitivity of pesticide detection were also performed these days (Li et al. 2019; Ji et al. 2020). Chemiluminescence immunoassay is another technique for pesticide residue analysis which can be used in conjunction with many detection systems (Al Yahyai and Al-Lawati 2021). TiO2-CPE nanocomposites electrode provide very good sensitivity for the cypermethrin and sensitivity can be increased with the increase of anatase TiO2 concentration which can detect down to the level of ~0.1 ppm (Nurdin et al. 2019). Modified TiO2-CPE can also effectively detect fipronil pesticide (Maulidiyah et al. 2019).

8.5 Mitigation of Problems Associated with Pesticide Residue Analysis

8.5.1 Rules and Regulations on Pesticide Residues Mitigation

8.5.1.1 Global and FAO

Pesticide residue in ecosystem is one of the pressing issues which need to be dealt with proper manner. International code of conduct was first approved by FAO in 1985 whereas the fourth version of the same was approved in 2013 and published during 2014. The code has 12 articles and one annexure which comprised guideline of pesticide management, labeling, packaging, storage and disposal and other aspects which directly help in reducing pesticide residues (FAO/WHO 2014; FAO/WHO 2022). This code is especially for those countries who could not establish their own standards or the standards available are inadequate. Stockholm convention which entered into action on 2004 is a global treaty whose objective is to protect human and environmental health from exposure to Persistent Organic Pollutants (POPs). It prohibits or aims in the elimination of production, use, import and export of POPs with some exceptions. Similarly, Rotterdam convention was adopted in 1998 and entered into action from 2004. Its major role is to create obligation to implement Prior Informed Consent (PIC) which facilitates exchange of information about hazardous chemicals among the parties in order to protect human health and environment. Montreal Protocol which regulates and phase down 100 man-made ozone depleting substances (ODS).

Food and Agriculture Organization (FAO) of United Nations therefore has formulated guideline for pesticide management via various forums. Those were Joint Meeting on Pesticide Management (JMPM), the Joint Meeting on Pesticide Specifications (JMPS) and the Joint Meeting on Pesticide Residues (JMPR), where JMPM advices FAO and WHO on the International Code of Conduct on Pesticide Management and the development of its technical guidelines, JMPS recommends to FAO and WHO on the adoption, extension, modification or withdrawal of pesticide specifications and to develop guidance and procedures in establishing pesticide specifications, and JMPR provides scientific advice to Codex Alimentarius, who sets maximum residue limits (MRLs) for pesticides in food and feed. Before a Codex establish MRL, JMPR, FAO/WHO experts review toxicological data and data from supervised trials in accordance with good agricultural practice. JMPR also conducts dietary risk assessment and then only report to the Codex Committee on Pesticide Residues (CCPR) who is authorized for establishing Codex Maximum Residue Limits (MRLs) for pesticide residues in food items or in groups of food or feed which are part of international trade, which ultimately report to Codex Alimentarius Committee (CAC) for adoption as Codex Maximum Residue Levels (CXLs) (Fig. 8.4). Codex has established over 5200 MRLs covering 300 pesticides (Wieck and Grant 2021).

8.5.1.2 EU and US

European Union has formulated the regulation on 23rd February 2005 on maximum residue level of pesticides in or on food and feed of plant and animal origin (EU 2005) which has amended time to time as necessary. Similarly European Food Safety Authority (EFSA) has promulgated different technical guidelines to determine pesticide MRLs and has also set MRLs of different pesticides compounds on different commodities (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/mrls/?event=download.MRL). These MRLs have to be set in accordance with the guidelines set by the Environment Directorate, Joint Meeting of the Chemicals Committee and The Working Party on Chemical, Pesticides and Biotechnology based on Organization for Economic Cooperation and Development (OECD) MRL Calculator user guide (OECD 2011). OECD maximum residue limit calculator is harmonized among member organization for Economic Cooperation and Development. EU has regular monitoring program to assess the pesticide

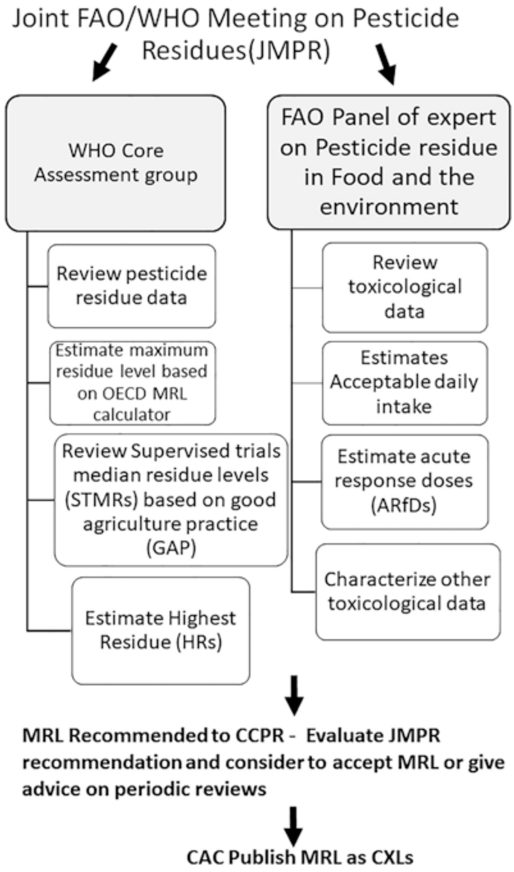

Fig. 8.4 Schematic representation of step-wise process of MRL setting by Codex Alimentarius Commission (CAC)

residue which is published yearly in the annual report by EFSA. Pesticide residue database for Europe can be assessed through https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/mrls/?event=download.MRL.

In United States, Environment Protection Agency is regulatory agency which formulated the Code of Federal Regulations (40 CFR), Title 40 which is entitled as "Protection of Environment." Before allowing the pesticide to use, EPA sets tolerance or maximum residue limits of pesticides. Office of Chemical Safety and Pollution Prevention of EPA advises to assess and regulate pesticides and toxic substances under various Federal acts (CFR 2021). MRLs of US could be access through https://www.fas.usda.gov/maximum-residue-limits-mrl-database.

8.5.1.3 South Asia

South Asian countries has a common forum called The South Asian Association for Regional Co-operation (SAARC) which includes Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. These SAARC countries have their national act or regulations to address pesticide management. All the SAARC countries are member of Codex Alimentarius Commission (CAC) and have delegated representative as National Codex Contact Point (NCCP) (WHO 2014).

Bangladesh has promulgated pesticide ordinance 1971, pesticide amendment ordinance 2007 & 2009, the pesticides rules 1985 and its amendment on 2010. Pesticide ordinance regulate pesticide registration, import, manufacture, repacking, sale, distribution formulation, and use of pesticide (http://bdlaws.minlaw.gov.bd/act-details-364.html). The ordinance provisioned the pesticide technical advisory committee which give advice to the government on technical matters. The Department of Agricultural Extension, Government of the People's Republic of Bangladesh provides the lists of registered and banned pesticides (The Bangladesh Gazette 1985).

Bhutan established The Pesticides Act of Bhutan, 2000 which is used to manage import, sale and use of pesticides. It also enforces rules and procedures related to pesticide management (RGB 2000) which ensure proper pesticide management. Bhutan Agriculture and Food Regulatory Authority (BAFRA) under Ministry of Agriculture and Forests has a goal to protect health and lives of plants, animals, humans and environment. It also envisions to safeguard biosecurity and ensure safe food for all. BAFRA is also responsible as National Codex Contact Point (NCCP) to establish minimum safety standard for food which is facilitated by Codex (Bhutan) Secretariat (https://www.bafra.gov.bt/index.php/codex-bhutan-2/).

Pesticides are regulated in India through the Insecticides Act, 1968 and Insecticides Rules, 1971 which has its third amendment, 2020 (GoI 2020). Further pesticide management bill, 2020 approved by the Union Cabinet seek to regulate the manufacture, import, sale, storage, distribution, use and disposal of pesticides in order to ensure use of safe pesticide and minimize risk to human, animal and environment, which will replace the pesticide act (Kumar and Reddy 2021). The pesticides' regulations in India are governed by two different bodies: The Central Insecticides Board and Registration Committee (CIBRC) and the Food Safety and Standards Authority of India (FSSAI). Food contaminants, toxins and residue level can be assessed for India through https://www.fssai.gov.in/upload/uploadfiles/files/Compendium_Contaminants_Regulations_20_08_2020.pdf (FSSAI 2020).

Similarly, Maldives manage pesticide use and regulate through Pesticide Inspection Manual, 2021 and Guideline for Pesticide Disposal which were published in 2021. Representative from Maldives Food and Drug Authority, Ministry of Health was regarded as Codex contact points.

Government of Nepal has assigned Department of Food Technology and Quality Center (DFTQC) to regulate and monitoring of the food and feed for quality assurance. DFTQC has a legal body that enforces food and feeds acts, regulations, directives, and other related issues. DFTQC, under the Ministry of Agriculture Development, has also been established as a Codex contact point (CCP) since 1974 (WHO 2014). NCCP of Nepal as a separate organizational structure was established in 2004 with DFTQC as the Secretariat office (WHO 2014). Pesticide residue is one of the components that DFTQC has a right to determine the MRLs of food and feed in the country. Plant quarantine and Pesticide Management Center (PQPMC) enforces the Pesticide management act 2019, new acts which replaced the existing Pesticide Act, 1991. PQPMC also issue license to register pesticide, declare list of banned pesticides and create awareness on the safe use of pesticide storage and disposal. Nepal Agriculture Research Council conducts research on pesticide residue (Giri et al. 2016). Maximum Residue Level (MRL) establishment needs a lot of researches on pesticide residue experiments with the application of good agriculture practice (GAP) (EFSA 2015; OECD 2016) and results of this pesticide residue are used to estimate MRLs (OECD 2016) with lots of procedure followed by experts (FAO 2016). The process for establishing of the commodities can take up to 24 months after the application is registered for approval to concern authorities (European Commission 2021). Therefore, a country like Nepal, can adapt the MRL level of Codex Alimentarius Commision (CAC), FSSAI, EU, etc. until it to be able to involve in rigorous research to the establishment of its own MRLs level. However, efforts have been made by various researchers and organizations to find out the residue of pesticides in agriculture commodities which gives a generalized overview of pesticide residue status in Nepal (Aryal et al. 2020). With thorough review and discussion with an expert, DFTQC, Nepal has established MRLs for different vegetables, and fruits in Nepal (DFTQC 2022) which helps facilitate the trade.

Agriculture pesticide rules, 1973 of Pakistan deals with the Registration of pesticide formulation of pesticide, Packing, Repacking, Refilling, Labelling, storage and use, and overall pesticide management issues in the country. Codex contact point for Pakistan is the Ministry of National Health Services Regulation and Coordination (MoNHSR&C), Islamabad, Pakistan. Pakistan National Food Security Policy has also addressed the issue of pesticide management and pesticide residues problems in the food supply chain of fruits and vegetables that exceed above maximum residual limits (GoP 1973).

Democratic Socialist Republic of Sri Lanka has promulgated the Control of Pesticide Act and Pesticide Technical and Advisory Committee Rules in 1980 which directs to constitute a pesticide registrar who has licensing authority for pesticides. This act also envisaged a committee which advise Registrar on pesticide registration, formulation, import, sale, storage, and use of pesticide and other related matter of pesticide management. Ministry of Health (MoH) is designated Codex Contact Point (CCP) for Sri Lanka. The NCCP in Sri Lanka was established in 2005. Maximum residue limits for pesticide in food was standardized by Sri Lanka Standard Institutions (SLSI 2021).

8.5.1.4 Other Asian Countries

In Indonesia, the NCC is led by the National Standardization Agency of Indonesia (NSAI); NSAI is the Codex Contact Point (CCP) for Indonesia. The Director of Food Safety at the Food and Drug Administration (FDA) is on the role of the new Codex Contact Point (CCP) for Myanmar and the Food Division of FDA is providing administrative services to the CCP.

The National Bureau of Agriculture Commodity and Food Standard is in charge of the Codex Contact Point (CCP) of Thailand. Controlling the quality and safety of raw materials used for food production, transportation, preparation, and selling to consumers as well as imported raw materials and food products are the responsibility of the Thai FDA under the Food Act of 1979.

Ministry of Food and Drug Safety, Food Standards Division, Korea Food and Drug Administration established MRLs for specific crops or crop groups and processed food in Korea (http://www.foodsafetykorea.go.kr/foodcode/index.jsp). The pesticide residue database for South Korea can be assessed through https://www.foodsafetykorea.go.kr/foodcode/02_01_02.jsp or https://faolex.fao.org/docs/pdf/kor190507.pdf.

8.5.2 Policy-Related Reform on Residue Mitigation

Access to advanced pesticide application and residue measurement equipment is limited in less developed countries. Consequently, the risks of pesticide exposure are likely to be higher. All the member countries should abide by the rules and guidelines set by FAO/WHO such as the "International code of conduct on pesticide management" (FAO/WHO 2014), "guidelines on retail distribution of pesticides with particular reference to storage and handling at the point of supply to users in developing countries" (FAO 1988), and other related guidelines related to pesticide management. But Low and mid-level-income countries' capabilities are required to be increased with the technical and financial support for them to be able to adapt to the pesticide management guidelines and also need technical guidance in setting MRL. Since setting MRL by country needs rigorous research and laboratory analysis with high precision having good laboratory practices, low-income and developing countries can adapt to Codex and the Codex MRL should be harmonized among all countries which have even stringent MRL levels. Yeung et al. (2017) have categorized the countries from group A to D depending upon the use of Codex MRLs and give some suggestions on how to harmonize MRL among trading partners. This could facilitate both trading as well as the risk associated with consumers. The PAN (Pesticide Action Network), FAO/WHO/CAC, WTO, OECD etc. can take initiative in global harmonizing MRL, GAP, residue analysis, application equipment, and procedures.

8.5.3 Good Agricultural Practices (GAP)

Good Agricultural Practices (GAP) arises from the need of producing healthy products without harming the environment. Adoption of GAPs may be applied to production and postharvest systems. They are applied through sustainable agricultural methods. GAP aims for the combined application of IPM (Integrated Pest

Management) and ICM (Integrated Crop Management). The application of Hazard Analysis in Critical Control Points (HACCP) is emphasized in GAP (ITESDES 2018).

The public standards for GAP are to be harmonized in production as well as post-harvest practices among the countries to ensure safe and quality food intake in general.

8.5.4 Reduction in the Use of Pesticides in Crop Production

The adoption of pest preventive cultural practices is an important strategy to avoid or minimize the pest's impact on the crop and reduce pesticide use. Cultural control practices are the regular farm operations that are used to destroy the pest or prevent the plant from damage. Several methods of crop cultivation have been practiced such as field sanitation, crop rotation, soil solarization, alteration of time of planting and harvesting, use of resistant varieties, intercropping, mixed cropping, mulching, deep tillage, etc. (Karaye et al. 2017). This method is most effective when the targeted pest is monophagous or oligophagous and does not disperse rapidly in the environment. This is the most important component of IPM (Integrated Pest Management), which emphasize an environmentally friendly method of pest control, pest prevention, and control prioritizing on alternative pest control methods and keeping the use of chemical pesticide as the last option. Jepson et al. (2020) has develop a system to categorized pesticide based on their hazards and grouped 243 pesticides of lower risk that could require only single layer PPE which have been in use in IPM program in US since 2016. Safer pesticide use could have less impact on human and environment. IPM programs can lead to reductions in the frequency and dose of pesticide use (Shahraki et al. 2011). Barrera (2020) emphasize changes in IPM strategies where we have to approach for holistic pest management considering socio economic aspects of farmers and interaction of pest problem with other elements of socio-environmental system. Problem of pesticide residue in Low-income and middle income countries arise because of their improper use which can be reduced by implementing IPM which ultimately can lower the risks of pesticide contamination to environment and exposure to farmers and consumers (Dahal et al. 2020). The FAO has launched three regional IPM programs comprising Asia, Near East and West Africa with several national projects, which provide technical assistance in capacity building and policy reform and facilitate collaboration among the nations (FAO 2022).

Suppression of pest population by using different manual devices is the new but widely used to keep pest population below damage level. It includes various practices, such as hand picking, trapping and use of suction devices, clipping, pruning, screening or setting barriers, manipulation of temperature and relative humidity, etc. (Oseto 2000). The use of traps may involve the use of pheromones that disturbs the natural mating cycles of the pest. These are the some lethal or some non-lethal pest control options without the application of chemicals in the crop.

The use of biological control agents could be the best option for protected cultivation (Van Lenteren and Woets 1988). Traditionally, the most important biological control agents are predators, parasitoids, and pathogens (Hawkins et al. 1997). Biological control involves three major techniques viz. introduction, conservation, and augmentation (Eilenberg et al. 2001). If there is a lack of natural predator populations like lady beetles, mantids, spiders, etc. can be released in the field in inundative or augmentative ways. Additionally, parasitic wasps (parasitoids) and other pathogens (virus, bacteria, fungus, nematode, protozoa) can be applied as pest control agents. For instance, the use of NPV to control European corn borer, the use of lady beetle to control aphids, and *Trichoderma* to control a broad range of plant pathogenic fungi. Bio-pesticides are more favorable and pest specific than conventional pesticides.

The restriction on the number of pesticide applications over time and space is recommended to minimize the risk of chemical pesticides. Application of pesticides based on the economic threshold level of the pest, alteration of pesticides with a different mode of action, pre-harvest interval (PHI), and use of pesticides with appropriate equipment at the most vulnerable stage of the pest life cycle are the important combination of pest management methods. The selection of minimally hazardous pesticides and avoiding HHPs, pesticide use by only licensed users, are other effective ways to manage pests by lessening the chance of pesticide resistance and pest resurgence.

8.5.5 Public Awareness Programs

In most cases, the rejection of consignment from the importing country is due to a higher level of pesticide residue than the determined MRL of that country. It occurs due to unknowingly using high doses of pesticides just before harvest or after harvest leaving more quantity of residues in the produce. In this situation, it is necessary to have appropriate knowledge of MRL and GAP on the producer's and trader's levels. The training and workshops on a regular basis need to be organized by the corresponding bodies so that the respective stakeholders can update their knowledge about the latest national and international regulations that are accepted for every farming method in the world. To increase the adoption of IPM or ICM strategies, it is necessary to focus on the educational and motivational programs for farmers by the implementing agencies (Rahman 2012). It is important to be aware of the effects of using harmful pesticides and the importance of alternative pest control methods (van Eeden and Korsten 2013).

8.5.6 Residual Detoxification by Transformation

Among pesticides, organophosphorus insecticides (OPIs) are the most common broad-spectrum insecticide that is globally used in agriculture (Ragnarsdottir 2000). They account for about 34% of worldwide insecticide use (Ning et al. 2021).

Carbamates are also important in agriculture due to their broad spectrum activity but are degraded relatively easily and generally have a low degree of toxicity to humans (Wolfe et al. 1978). In nature, various biotic and abiotic transformations of chemicals can detoxify the harmful chemicals. The natural lactonase enzymes like Phosphotriesterase- like Lactonases (PLLs) could be used as biocatalysts for OPIs degradation and remove toxic residues from the environment in a safer manner. Besides this, bleach treatment, alkaline hydrolysis, oxidation, and reduction are important activity that could be employed for detoxification and metabolites formation of OPIs (Paidi et al. 2021). Simple techniques like washing, blanching and peeling in household condition and thermal treatments in small scale industries are effective for reducing pesticide residues. Further use of novel technologies like cold plasma, pulsed electric field, irradiation, hydrostatic pressure and ultrasonication have been in use to lower pesticide residues (Mir et al. 2022).

8.5.7 Reduction in the Pesticide Exposure

There are many instances in certain stages of pesticide life cycle, i.e. from formulation of rules, manufactures to use and disposal of pesticide waste, exposure is inevitable if safety measure are compromised (Van den Berg et al. 2020). Similarly, major route of pesticide exposure to humans in the world is also through the consumption of food products (Claeys et al. 2008; Drouillet-Pinard et al. 2011). Various household and industrial strategies could be used to reduce pesticide exposure like washing, peeling, blanching, and thermal treatment. Nowadays, some novel technologies have been used to reduce pesticide residue in agricultural goods depending on the type of pesticide residues like cold plasma technology, pulsed electric field, and irradiation methods. In cold plasma technology, plasma (apparently neutral ionized gas consisting of ions, free electrons, atoms, and molecules) are in thermal non-equilibrium and degrade many pesticide residues in various commodities (Sarangapani et al. 2017; Misra 2015). In pulsed electric field method, a short burst of electricity is used to degrade pesticide molecules (Mosqueda-Melgar et al. 2008). The gamma radiation at various doses can also degrade pesticide residues (Dessouki et al. 1999).

It is important to protect the user from direct exposure to pesticides during application. Using proper equipment and wearing appropriate clothing provides a layer of protection during the handling, mixing, application, and storage of pesticides (Yarpuz-Bozdogan 2018). The type of equipment and the clothing depends on the type of pesticides being used. The user should follow all the directions and instructions indicated on the labels. The personal protective equipment (PPE) should be clean, and in good condition. The PPE includes gloves, chemical goggles, apron, waterproof boots, mask, hat, and ear plugs. The equipment should be thoroughly cleaned with soap and water after every use before storage to keep ready for next use. The empty containers should be disposed of according to the instructions provided in the pesticide packing. The safe storage of pesticides requires attention to the location and features of storage. The pesticide storage should be located at a safe location without any kind of leakage and made with fire-resistant materials. Entry to the storage should be limited to authorized persons only. Herbicides, insecticides, and fungicides should be stored at a separate location in the storage area to avoid cross-contamination and misuse.

8.5.8 Product Inspection and Traceability

The practice of inspecting materials delivered in the market has been used in many countries for a long time to ensure the quality and safety of goods. Government regulations requiring product inspection or traceability (with the database of production) exist in many countries. The objective of inspection or traceability is to avoid the double cost of effect from unsafe food and the associated cost of buying. The provision of pesticide residue testing at border points or at the market can curb the excessive use of pesticides. There are many events of the consignment being rejected due to the presence of pesticides above MRLs.

8.6 Conclusion

There is challenge to feed the growing population as safe food which is the fundamental food right of the humans. To increase the food production, use of different inputs including pesticides seems inevitable which was evident from the increase in global pesticide use. The rate of increase of global pesticide use seems to be higher in low income and food deficit countries than developed nations. So there is a great challenge to increase food production for growing population while maintaining the toxin level below MRLs. Considering the risk associated with improper use of pesticides like resurgence of pest, outbreak of secondary pests, pesticide residues, environmental contamination and risk to human health, it is high time to opt many of the mitigation options to reduce pesticide related hazards. Country specific rules and regulations for pesticide management should be strictly enforced. Crops should be grown with good agricultural practice following integrated pest management strategies which certainly resolve the issue of exceeding MRLs to some extent. Food and agriculture trading around globe should not be hindered because of pesticide residue related problems. Exporting goods are restricted to export due to stricter standard set by importing countries where developing countries suffer. Pesticide regulation including different MRLs of different countries needs to be harmonized for smooth trade. Further technical and financial support is required for the low income and developing countries to be able to meet the international standard. All the international forums like FAO, WHO, OECD, PAN, WTO, and international conventions could play a vital role to facilitate activities related to pesticide management, particularly for low-income and developing countries.

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Part III
Biotechnological Advancement and Sustainable Food and Nutrition Security

Chapter 9
Plant Breeding Strategies and Methods for Food Security: Review on the Technology

Bal Krishna Joshi, Hari Kumar Shrestha, and Dipendra Kumar Ayer

9.1 Introduction

The primary necessity of human beings is food which needs to produce using diverse agricultural genetic resources from suitable environments for supplying balanced nutrients. Along with the advances in agricultural science, particularly, genetic manipulation, there is a hope to achieve food, nutrition and environmental security worldwide. However, meeting the expected increases in food and nutrition demand remains a big challenge. Crop breeding (i.e., genetic manipulation) had contributed to about half of the average global production increase in cereals that were achieved under the Green Revolution (Joshi 2017a, b; Tollenaar and Lee 2006). The other half came from other agricultural inputs such as the use of fertilizers, pesticides, irrigation and expansion of cultivated areas. Intensive agriculture relies on natural resources to a great extent and the degradation of the natural resource base could limit the scope of production ability for the future generations (Chaudhary et al. 2020; FAO 1999; Joshi et al. 2020a), emerging the sustainability issues in agricultural practices over the long run. This indicates the increased role of crop diversity and breeding in meeting the global demand for agricultural production.

FAO (2009) reported that the world's food production must increase by 70% in 2050 to feed a projected extra 2.3 billion people. The demand for cereals, both for food and animal feed, is projected to reach some 3 billion tons by 2050. To meet the

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production increment by 2050, only 10% is expected from an expansion in arable land and the remaining therefore should come from a high yield. In the past, the increased production of cereals enabled many countries to feed their populations (the doubling of yield per hectare was observed between 1960 and 1985) (Eliazer Nelson et al. 2019). In the current decade, the yield increment of major crops is relatively very low as compared to the population growth rate (Fig. 9.1). Land area increment and cereal productivity are given in Fig. 9.2. With an increase in arable land, cereal production is not increasing at the same rate (Fig. 9.2) which indicates the need for improving the crops for their higher yield than just increasing the

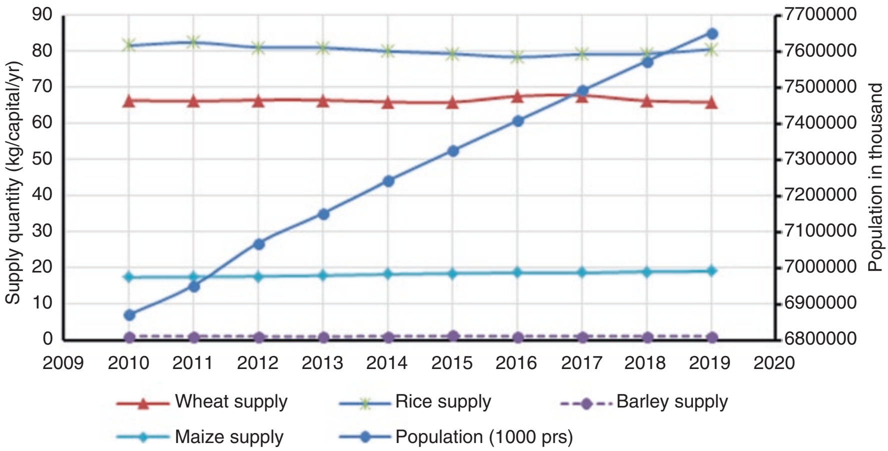

Fig. 9.1 Population and major crop production supply over the last decade. (Source: FAO (https://www.fao.org/faostat/en/#home))

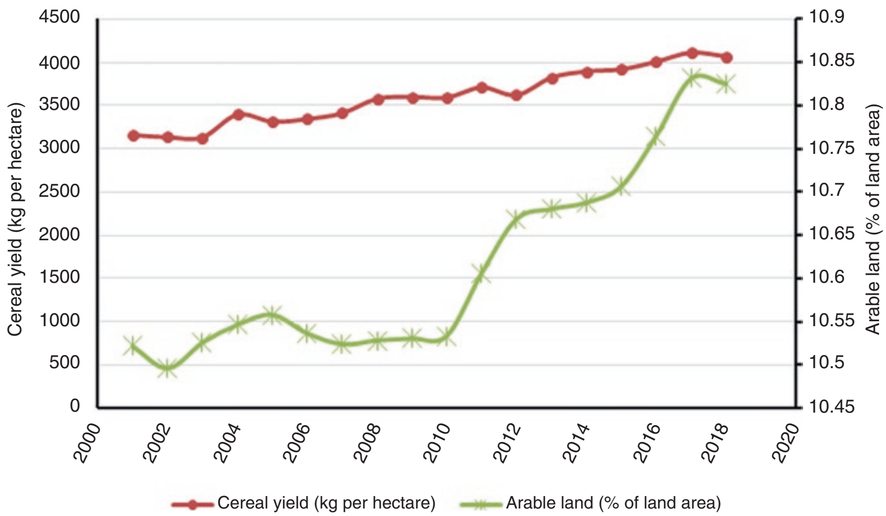

Fig. 9.2 Total arable land (% of land areas) and cereal yield (kg per hectare). (Source: World Bank Development Indicators https://data.worldbank.org/indicator?tab=all)

cultivated land area. Even the total production of major crops is not increased in this decade (Fig. 9.3). It indicates that the yield of these crops has reached a plateau level.

Among the three approaches (area expansion, management and genetic improvement) to increase food production (Fig. 9.4), genetic improvement is the best approach for food, nutrition and environmental security. However, genetic advancements introduced high-yielding varieties of mainly rice, wheat and maize to increase food production and alleviate hunger, and in contrast, several indigenous crops were largely ignored. This is because the human relies on just three crops (rice, wheat and

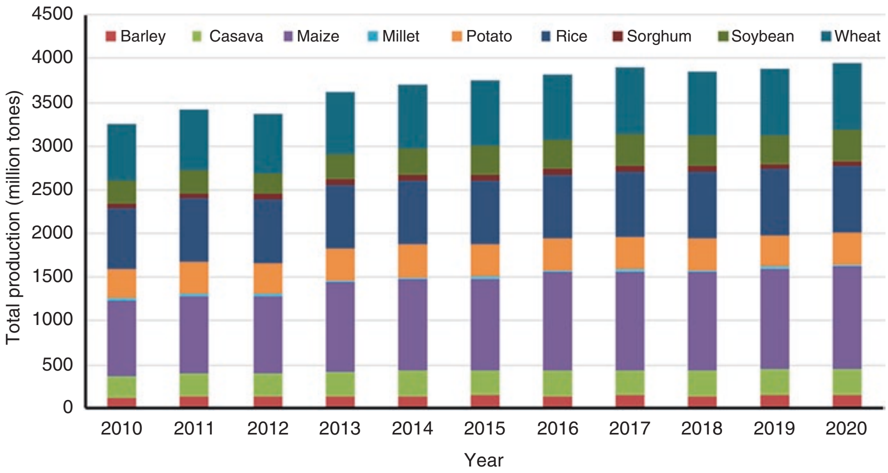

Fig. 9.3 Total production of major crops in the world. (Source: FAO (https://www.fao.org/faostat/en/#data/QCL))

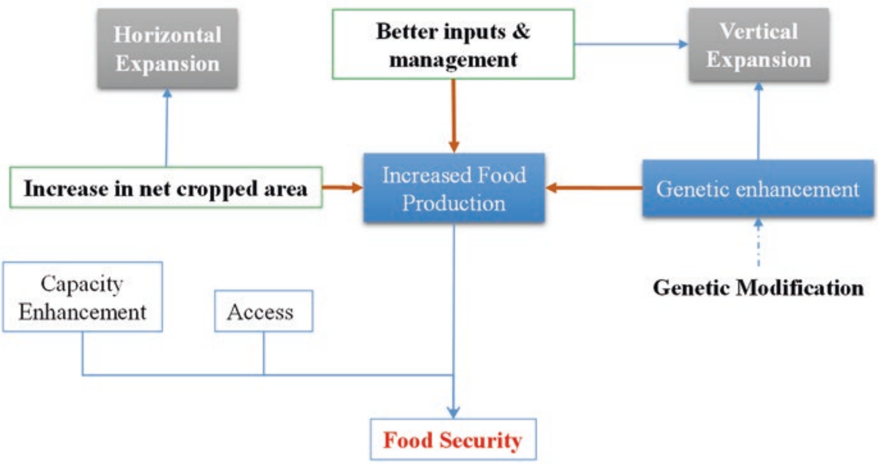

Fig. 9.4 Food security strategy and option

maize) for nearly 60% of their plant-derived calories (https://www.fao.org/3/y5609e/y5609e02.htm). The worldwide situation of food deficit and undernourishment are depicted in Figs. 9.5 and 9.6 respectively. The degree of food deficit is increasing each year. One in three people suffers from micronutrient deficiencies and almost 2 billion people are overweight or obese (https://www.fao.org/news/story/en/item/455867/icode/). Agricultural production is expected to reduce by 2% and demand will increase by 14% every decade till 2050 (https://www.ipcc.ch/report/ar5/syr/). In this situation, the food and nutritional supply will further worsen. Therefore, crop improvement by manipulating the genotypes is the most important strategy for food security across the world.

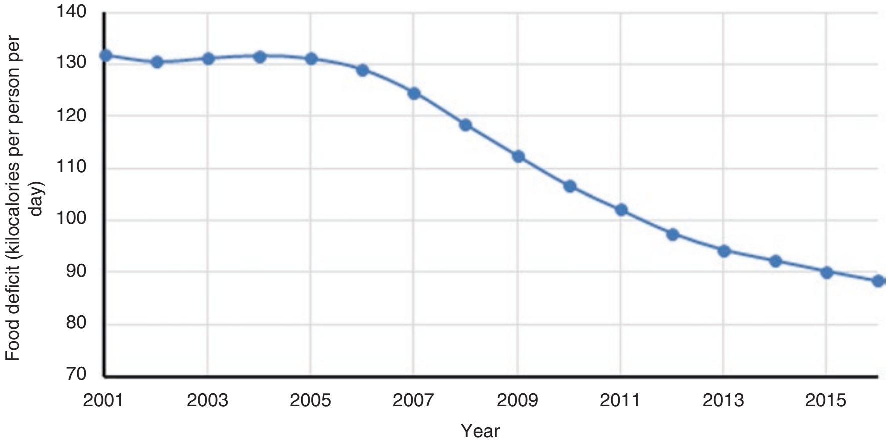

Fig. 9.5 Food deficit (kilocalories per person per day) worldwide over the years (Source: World Bank Development Indicators (https://data.worldbank.org/))

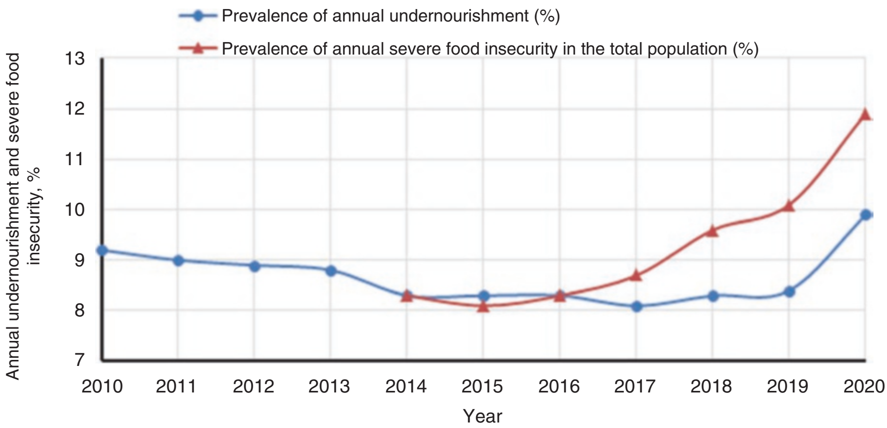

Fig. 9.6 The annual prevalence of undernourishment and severe food insecurity percentage. (Source: Food and Agriculture Organization (FAO) (http://www.fao.org/faostat/en/#data/FS/visualize))

9.2 Crop Biodiversity and Technological Advances

Genetic variation facilitates crop improvement the most. The higher the degree of genetic diversity, the more is the chance of getting superior genotypes concerning different traits. Natural variation is now almost fully exploited in major crops. If there is limited natural genetic variation, variations are being created artificially either through mutagens or crossing among varieties, species and even genera, or transferring the gene of interest. There are 250,000 to 300,000 known edible plant species in the world, however, only 4% i.e., 150 to 200 species are used by humans (FAO 1999). Among them, only rice, maize and wheat contribute about 60% of calories and proteins obtained by humans from plants. Crop improvement works also got priority to these three crops over the years and locations. Only 12 crops and five animal species provide 75% of the world's food. Advanced breeding techniques are only being used in a few crop species. Most of the natural crop diversity is conserved ex-situ in static conditions. A total of 63, 95, 166 accessions are available through ITPGFRA-MLS (known as the global gene pool) for utilization in breeding programs (https://mls.planttreaty.org/itt/index.php?r=stats/pubStats). Most of them are of rice, wheat and maize species. With due focus and priority to only a few crop species, only a few varieties have been grown in many countries. This resulted in the loss of about 75% of crop genetic diversity worldwide mainly because of growing and disseminating genetically uniform, high-yielding varieties (FAO 1999).

Many countries now have adapted strategies to minimize genetic erosion and diversify their food systems. The scope of crop breeding has extended to other species including both crops and plants. Crops include all domesticated species under the kingdom Plantae and plants cover wild species under the kingdom Plantae. These are collectively called agricultural plant genetic resources (APGRs). The classification of these resources has been represented in Fig. 9.7 based on their economic uses. All these groups need to consider in the breeding programs that help to secure food, nutrition, and the environment worldwide.

Natural and artificial selection remain as the most important practice to develop high-yielding varieties. To assist the selection process, breeders used only phenotype in the earliest period. With the progression of scientific understanding and technological advancement, breeders have started using genotype, metabolites, nutrient profiles as well as omics technology for developing desired genotypes (Fernie and Schauer 2009; Lenaerts et al. 2019). The key milestones related to crop improvement are represented in Fig. 9.8 along the year. All these advances have significant contributions to developing superior varieties for some economic traits. These are also equally important in creating genotypes with resilient to climate change.

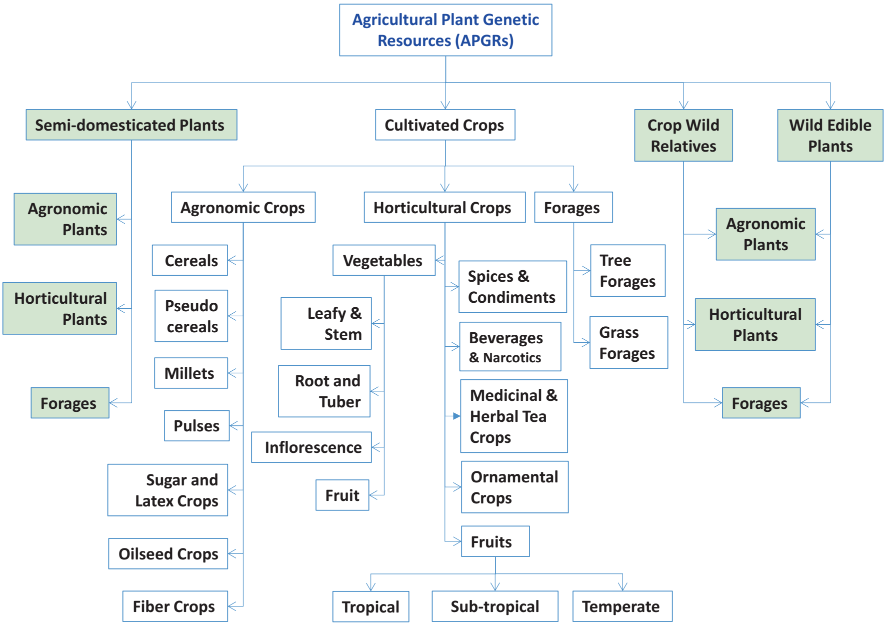

Fig. 9.7 Plant classification based on economic value and uses. (Adapted from Joshi and Shrestha 2017)

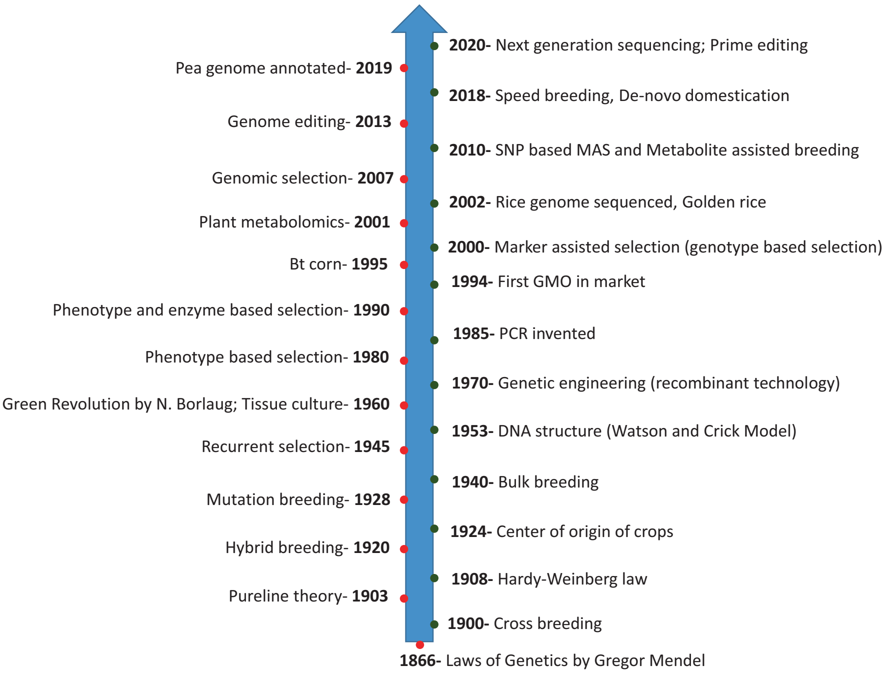

Fig. 9.8 Key milestones related to crop improvement

9.3 Crop Improvement Strategies and Methods

The strategy for crop improvement changes over time and differs among breeding institutes and countries. Developing an optimum strategy is very important to meet the objectives within a given time frame. A major aim of crop improvement is to increase economic yield; however, it depends on different factors. For example, in biotic (e.g., diseases and insect pests) and abiotic (e.g., temperature, drought, salinity and light) stresses, the major aim would be to develop resistance or tolerance varieties to these stresses. The strategic options for improving crops are wide vs specific adaptation, mono vs polymorphic variety, broad vs narrow genetic base variety, participatory vs non-participatory method, evolutionary vs static population, etc. In the past, the crop improvement strategy was to develop widely adapted monomorphic variety across the country, or for the region and even the world. Such varieties had a very narrow genetic base and were commonly developed by breeders with very limited involvement of farmers. The crop diversity in the field had been collected and conserved ex-situ. From this diversity, a single homozygotes variety was developed expecting to grow in large areas. This system ignored the importance of diversity in the field. These strategies increased the dependency for varietal seeds on other institutes and countries and replaced local crop diversity (Chaudhary et al. 2020; FAO 1999; Joshi 2017a; Joshi et al. 2020a, b). Many breeders focused on developing stable and high-yielding varieties across diverse environments. This limits the yield advantages of variety in a particular environment. A breeding strategy can also be either improvement on a single trait or multiple traits.

Then the strategy in many countries focused on developing site-specific polymorphic varieties with a broad genetic base. The involvement of farmers in the crop improvement process from the very beginning also got priority in many breeding programs (Joshi 2017a). This is called participatory plant breeding. Recently, the breeding strategy has been changed from a developing static population to an evolutionary population (Joshi et al. 2020a). With the multiple strategies, different approaches are being used by different breeding institutes, for example, conventional crop improvement approaches, fast track breeding, hybridization among close relatives as well as distantly related genotypes, phenotype-based selection, and genotype-based selection including gene editing. Crop improvement activities are carried out in the lab and field. During the field test, the trials are conducted both on-station and on-farm. Many improved varieties have a high amount of carbohydrates rather than balance nutrients (Joshi et al. 2020c) which trigger to focus on nutritionally balanced varieties.

Crop improvement is mainly concerned with the manipulation of the genetic makeup of existing landraces and varieties. Broadly four methods are being used to manipulate the genetic makeup (Fig. 9.9). Vertical gene transfer and mutation are old and very common methods of crop improvement globally used for many crop species. Horizontal gene transfer is an advanced technology through which genes of interest of any species can be transferred to the target genotype (Fig. 9.9). Grafting, also called organ transplant is a simple technique to change the genetics of rootstock in crop species. This is very useful for managing soil-borne diseases and insect pests along with better nutrient uptake.

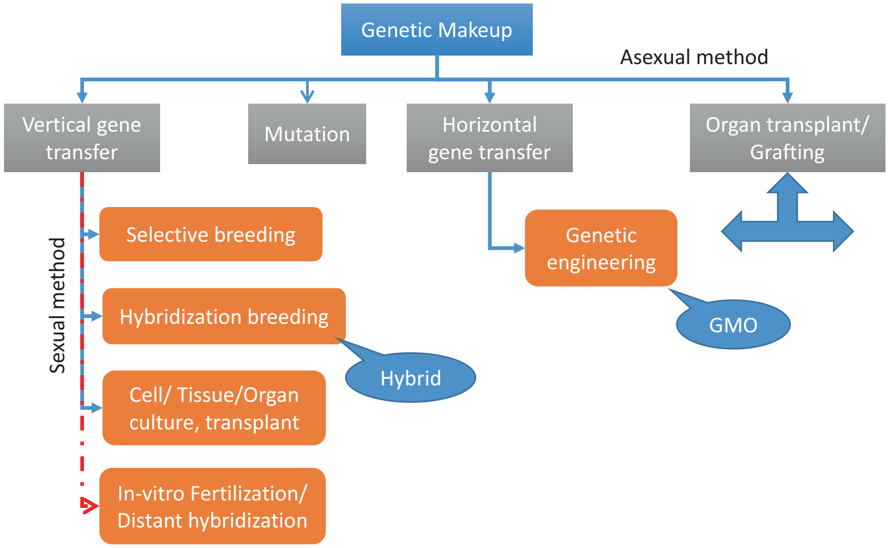

Fig. 9.9 The basic technology for genetic manipulation of crop genetic resources (red line means not commonly used, arrow below organ transplant means traits not inherited). (Adapted from Joshi 2017a, b)

Several different breeding methods have been developed and are used to improve the crops (Breseghello and Coelho 2013; Joshi 2017a, b; Lenaerts et al. 2019; Munaweera et al. 2022; Razzaq et al., 2021). The application of these methods depends on the types of crops used and localities e.g., in lab, glasshouse, on-station, or on-farm. Broadly breeding methods differ among three types of crops based on the mode of reproduction (self-pollinated, cross-pollinated and clonally propagated crops). The general scheme of crop improvement is provided in Fig. 9.10 for self and cross-pollinated crops. Clonal selection is a very common means of improving vegetatively propagated crops e.g. potato, apple, banana, etc. A brief description of Crop improvement methods is listed in Table 9.1 along with a brief description. The selection of methods depends on mainly the objectives of the breeding, crops and facilities available in the breeding center.

9.4 Biotechnological Advances

The current world population of 7.95 billion in 2022 is expected to reach 10 billion in 2057 (Worldometer 2021). Therefore, feeding the expected additional 2.1 billion people is a challenge in global plant breeding. Plant breeding is mainly concerned with the genetic improvement of crops through hybridization, screening, and selection of advanced lines (Adlak et al. 2019). During the last century, crop plants have been improved for increasing the yield in coordinated ways through classical plant

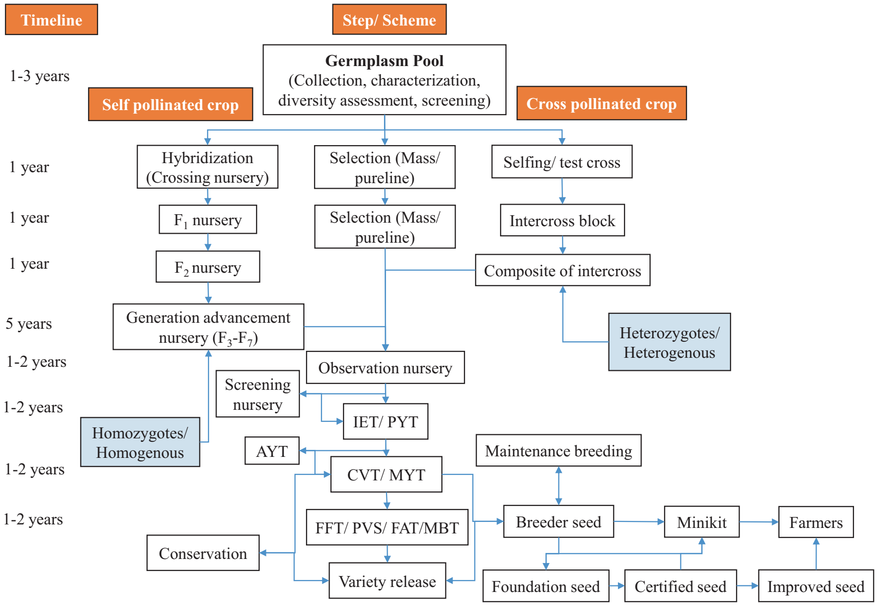

Fig. 9.10 Conventional methods of crop improvement and dissemination. Foundation seed is also called source seed, and certified seed as labeled seed. In another seed class, the foundation and certified seeds are equivalent to source and labeled seeds. (Adapted from Joshi 2017a, b)

Table 9.1 Crop improvement methods

SN	Crop improvement method	General definition	Important features
1	Allele and gene mining	Discovery of superior alleles, through 'mining' the gene of interest from diverse genetic resources	Genetic resources collections are screened for allelic variation by the 'tiling strategy' using DNA chip (microarray or biochip) technology
2	Anther culture	Regeneration of plant from anther	In-vitro technique for production of haploid and doubled haploid plantlets
3	Anti-sense RNA	One of the approaches that are used for the inhibition of gene expression or downregulation of a gene	Prevent translation of complementary RNA strands by binding to them. It plays an important role in generating high-yielding, disease and pest resistant, high nutritional value, and stress-tolerant crop varieties
4	Backcross breeding	A crossing of a hybrid with one of its parents	Transfer of single gene to target genotype
5	Biofortification	The process of developing a crop with higher levels of essential nutrients in its edible parts	Through selective breeding or biotechnological approaches

(continued)

Table 9.1 (continued)

SN	Crop improvement method	General definition	Important features
6	Bulk selection	Segregating population is grown in bulk with or without selection	A part of the bulk seed is used to grow the next generation and individual plant selection is practiced in F_6 or later generations
7	Cultivar mixture	Growing more than one variety or landrace together by mixing seeds	Create high intra-varietal diversity and create buffering for many stresses
8	Domestication	Process of making wild plants responsive in a human management environment	Adaptation of a plant from a wild or natural state (as by selective breeding) to life in close association with humans
9	Double haploid breeding	Production of diploid plants from pollen or egg cells or other cells of the gametophyte, then by induced or spontaneous chromosome doubling	Pure homozygous lines require a shorter time to produce in comparison to classical *breeding*
10	Embryo rescue	An in-vitro technique to protect the weak, immature, and hybrid embryo and promote it to develop into a complete plant	Useful for distantly related plant species to cross
11	Evolutionary plant breeding	Development of crop populations with a high level of genetic diversity and subjected to natural selection	A large number of different genotypes can combine including segregating lines to create a resilient population
12	Gene (genome) editing	Technologies that allow genetic material to be added, removed, or altered at particular locations in the genome	Ability to make highly specific changes in the DNA sequence of a living organism, essentially customizing its genetic makeup
13	Genetic engineering	The artificial manipulation, modification, and recombination of DNA or other nucleic acid molecules to modify an organism or population of organisms	Uses of distantly related genes in species to modify their genetic makeup, which natural not possible to combine
14	Genome-wide association studies (GWAS)	Scanning several hundred thousand markers across the complete sets of DNA of many plants to find genetic variations associated with a particular trait.	An observational study of a genome-wide set of genetic variants in different individuals to see if any variant is associated with a trait
15	Genomic assisted breeding	The integration of genomic tools withhigh throughput phenotyping to assist breeding practicesthrough molecular markers to facilitate the prediction of phenotype from genotype	The selection of beneficial alleles for multiple loci throughout the genome
16	Heterosis breeding	Development of hybrid showing hybrid vigor through using diverse parents	Hybrid performs better than either parent, hybrid is developed through heterosis breeding

(continued)

Table 9.1 (continued)

SN	Crop improvement method	General definition	Important features
17	Hybridization	Crossing of two or more genetically dissimilar parents	Artificial transfer of pollen from one parent to another parent to produce hybrids
18	Ideotype breeding	A method of crop improvement that is used to enhance genetic yield potential through genetic manipulation of individual plant character	Model plants or ideal plant types for a specific environment
19	Introduction	Taking a genotype or a group of genotypes into a new place or environment	High-yielding varieties developed elsewhere are brought to target new environment
20	Maintenance breeding	Principles and method of breeder/nucleus seed production and maintenance	a breeding procedure followed to maintain the genetic purity of the variety or parents of hybrid.
21	Marker-assisted selection	An indirect selection process where a trait of interest is selected based on a marker linked to a trait of interest, rather than on the trait itself	DNA marker closely linked to target trait is used to select at any crop stage
22	Mass selection	A large number of plants of different desirable phenotypes are selected and their seeds are mixed to constitute a new variety	The plants are selected based on their appearance or phenotype. The population obtained from the selected plants would be more uniform than the original population
23	Metabolomics assisted breeding	Selection of genotype based on metabolites, for developing variety which produces the higher and superior metabolites	A systematic screening of crops to know the metabolic and chemical footprints of plant regulatory processes
24	Micro-propagation	The artificial process of producing plants vegetatively through tissue culture or cell culture techniques	Produce virus-free plantlets, and a large number of plantlets within a short period
25	Molecular breeding	The use of genetic manipulation performed at DNA molecular levels to improve characters of interest in plants	It includes genetic engineering or gene manipulation, molecular marker-assisted selection, genomic selection, etc. application of molecular biotechnologies, specifically molecular markers, in combination with linkage maps and genomics, to alter and improve plant traits based on genotypic assays
26	Mutation breeding	The process of exposing crops to chemicals, radiation, or enzymes to generate mutants with desirable traits	Create variation in crops and many different new genotypes can be selected

(continued)

Table 9.1 (continued)

SN	Crop improvement method	General definition	Important features
27	Omics technology	Detection of genes (genomics), mRNA (transcriptomics), proteins (proteomics) and metabolites (metabolomics) in a specific crop sample	Very advanced technology for understanding and manipulating the genotype of any crop plant
28	Participatory landrace enhancement	Mass selection approach involving both farmers and breeders for locally available landraces on-farm	Help improve local landrace genetically maintaining a broad genetic base and quality
29	Participatory plant breeding	Selection of segregating materials in farmer's field involving both farmers and breeders	Interaction among farmers and breeders helps to select suitable genotypes from the segregating populations
30	Participatory varietal selection	An approach that provides a wide choice of varieties to farmers to evaluate in their environment using their resources for increasing production.	Individual farmers can select different genotypes as per their choice from among the few fixed genotypes on-farm
31	Pedigree selection	A breeding method in which the breeder keeps records of the ancestry of the cultivar	Established by crossing selected parents, followed by handling an actively segregating population
32	Polyploidy breeding	Development of variety with multiple sets of chromosomes over the diploid number	Induced chromosome manipulation targeting different ploidy levels
33	Protoplast fusion	Two or more protoplasts bring in contact and adhere with one another either spontaneously or in presence of fusion inducing chemicals	Also called somatic fusion, is a type of genetic modification in plants by which two distinct species of plants are fused to form a new hybrid plant with the characteristics of both, a somatic hybrid
34	Pure line selection	Selection and breeding of progeny obtained from superior genotypes for several generations to attain a pure line having desired characters	Genetically same with almost zero genetic diversity
35	Recurrent selection	Repeated cycles of selection and breeding aimed at gradual genetic improvement of a few key traits	Population improvement involves reselection generation after generation with the interbreeding of selects to provide for genetic recombination
36	Resistance breeding	Development of resistance or tolerant varieties to disease and insect pests using suitable genes	Diseases and insect pests do not affect the crop stands
37	Shuttle breeding	An extra generation is advanced each year by using a different field location	Two generations are advanced growing two times in the same year

(continued)

Table 9.1 (continued)

SN	Crop improvement method	General definition	Important features
38	Single seed descent	Selection of a single seed from each plant, bulking the individual seeds and planting out the next generation	The advancement of one randomly selected seed per plant through the early segregating stages
39	Space breeding	Space-grown plants are exposed to cosmic radiation and microgravity, which led to the generation of crop varieties with diverse genotypes and phenotypes arising from different cellular, subcellular, genomic, chromosomal, and biochemical changes	Mutation breeding exposes seeds to the region beyond the earth's atmosphere or beyond the solar system (space) to create superior crop varieties
40	Speed breeding	The manipulation of environmental conditions under which crop genotypes are grown, aims to accelerate flowering and seed set, to advance to the next breeding generation as quickly as possible.	Growing plants under continuous light (20–22 h). This allows plants to photosynthesize for longer, resulting in faster growth. With this technique, four to six generations of wheat plants can be grown per year instead of two generations under normal growth conditions
41	Stress tolerance breeding	Breeding approaches to improve several traits simultaneously for stress tolerance	Using abiotic and biotic resistance/tolerant genes
42	Transgenic breeding	Gene transfer between related or unrelated species and even between unrelated organisms	It permits gene transfer even between plants and/or animals, through genetic engineering

breeding techniques and numerous varieties of several crops have been developed across the world (Pandey et al. 2019). However, the conventional breeding approaches to improve crop varieties are considered a constraint due to genetic erosion, genetic drag, and reproductive obstacles, and take a longer time (6–12 years) (Adlak et al. 2019; Pandey et al. 2019). Therefore, considering the trends of current yield of crops, expected world population growth, and pressure on the environment, the yield-enhancing traits, including disease resistance, abiotic stress tolerance, biotic stress tolerance, and enhancing nutritional quality, and water use efficiency need to be developed stably and sustainably, which should be a major target of global plant breeding. Biotechnology tools make breeding methods more advanced by reducing the time to obtain improved varieties of desired traits. Therefore, there is an urgent need for the integration of both breeding and biotechnology tools to improve the yield, nutrition, and quality of crop varieties. Plant tissue culture, molecular breeding, and genetic engineering are the three major approaches to deal with crop improvement via biotechnology (Adlak et al. 2019). In addition, biotechnology has also greater role on conservation of agrobiodiversity (Joshi 2017b).

Plant tissue culture is a novel tool or an emerging field, which was invented by Gottlieb Harberlandt in 1902, is a culturing of any part of the plant (cells/tissues or organs) in the synthetic medium under an aseptic (sterile) environment or workplace, and controlled conditions of light, temperature and humidity in a laboratory or a greenhouse for improving the accessibility of existing germplasm and creating a new genetic variation for sustainable agricultural crop improvement, plant breeding, horticulture, fresh produce, medicinal or ornamental plants, industrial chemistry, forestry, and is a prerequisite for plant genetic engineering (Bonner 1936; Evans et al. 2003; Tazeb 2017; Loyola-Vargas and Ochoa-Alejo 2018; Vakhariya et al. 2019). The technique is also known as Micropropagation. The ability of plant cells or tissues to be totipotent is referred to as "totipotency". It can be applied for the culture of callus, organ, cell, cell suspension, anther or pollen, somatic embryogenesis, protoplast, shoot tip/bud & meristem, embryo and seed for generating clumps of shoots or the whole plants that are useful to develop new crop varieties in agriculture (Bonner 1936; Joseph et al. 1996; Singh et al. 2011; Waghmare et al. 2017; Loyola-Vargas and Ochoa-Alejo 2018; Adlak et al. 2019; Efferth 2019; Vakhariya et al. 2019; PCT 2020; Motolinía-Alcántara et al. 2021).

Molecular marker-assisted breeding (MAB), particularly molecular (DNA) markers are the powerful, practical, and best indirect selection for target genes at the DNA level, which will greatly increase the efficiency and precision of plant breeding. It is the use of molecular technologies with linkage maps and genomic approaches, to edit and improve traits of interest based on genotypic analysis. It has significant advantages compared with conventional breeding methods such as improving the genetic quality of different plant species very fast; however, it is not a replacement conventional system. Therefore, the integration of MAB into conventional breeding programs represents an optimistic strategy for future crop improvement (Jiang 2013). Since the 1990s, MAB has received increasing attention and has been extensively used in different crop species. The reasons for using MAB are to (i) allow indirect selection of desirable gene alleles without the confounding effects of environment, pleiotropic, or epistatic gene effects; (ii) enable discrimination between plants homozygous or heterozygous for a given gene; (iii) monitor the introgression of a desirable allele in backcrossing; and (iv) identify of recombinants exhibiting the least amount of linkage drag (donor DNA) (Rajcan et al. 2011).

The use of DNA markers in plant breeding includes marker-assisted selection (MAS), marker-assisted or marker-based backcrossing (MABC), marker-assisted gene pyramiding (MAGP), marker-assisted recurrent selection (MARS) and genomic selection (GS) or genome-wide selection (GWS) plays a crucial role in the improvement of high yielding crop varieties (Castro et al. 2003; Collard et al. 2005; Francia et al. 2005; Dwivedi et al. 2007; Goddard and Hayes 2007; Li et al. 2010; Luo and Yin 2013; Al-Khayri et al. 2015; Osei et al. 2018; Pandey et al. 2019; Kumawat et al. 2020).

Genetic engineering, also known as genetic modification or genetic manipulation, is the engineering of an organism's genes using a set of technologies for changing the genetic makeup of cells, including the transfer of gene(s) within the same species through the use of **cisgenic** approach or across species boundaries through the use of **transgenic** approach to producing improved or novel organisms (Schouten et al. 2006; Jacobsen et al. 2008; Karthikeyan et al. 2012; Shrestha 2017; Pandey et al. 2019). In general, genetic transformation contains two steps, including genetic cargo delivery and regeneration. The new DNA can be inserted randomly or targeted to a specific part of the genome. In crops/plants, it is the modification of specific gene(s) into the crop(s)/plant(s) genomes, incorporating desired single or stacked genes (gene pyramiding and multigene) with a construct for achieving novel crop(s)/plant(s) more efficiently than the conventional breeding system (Shrestha 2017). The new DNA is obtained by either isolating and copying the genetic materials of interest using recombinant DNA methods or by artificially synthesizing the DNA. It has opened new avenues to modify crops and provided new solutions to solve specific needs. The system has a great opinion to improve crop genotype with significant commercial values that include increasing yield, protecting from environmental threats by developing biotic (e.g., resistance to disease, bacteria and pests) and abiotic (e.g., temperature, drought, salinity, light) stress tolerances, improving the nutritional quality of crops (e.g., vitamins A, Zinc, protein) and developing non-food crops (e.g., molecular pharming, biofuels, bioremediation) (Shrestha 2017).

The use of **plant genetic engineering** such as transgenic, cis-genic, and **genome editing** such as zinc finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs) and clustered regularly interspaced short palindromic repeats (CRISPR/Cas9) have made it possible to transfer the gene from related, unrelated plant species and even from non-plant organisms to crop plants (Nemudryi et al. 2014; Bonawitz et al. 2018; Ei-Bassyouni and Mohammed 2018; Ran et al. 2018; Kumari et al. 2021; Zhang et al. 2021). The advances in the biotechnological plant breeding approaches have efficient options to improve target crop varieties with significant yield, nutrition, and quality attributes. In addition, conservation biotechnology has a greater role in making access to existing crop diversity, particularly endangered species, and landraces in the future (Joshi 2017a, b). Genetic engineering can also be used to remove genetic materials by knocking down a gene with RNAi to produce a desirable phenotype (Capecchi 2001). The term transgenic is favored by scientists but GM has been adopted most widely by non-specialists. Currently, it is a controversial public concern and reduces the market charm; therefore, the development of the marker-free system is a priority that can avoid selectable and marker genes in the target product(s).

9.5 Breeding for Food Security

Food security is one of the major global challenges that we face as access to the basic amount of food necessary for a healthy life must be achieved by the growing population. Food security, as defined by the United Nations Committee on World Food Security, means that all people, always, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life. Over the coming decades, a changing climate, growing global population, rising food prices, and environmental stressors will have significant yet uncertain impacts on food security (IFPRI 2022). Greater and more consistent crop production must be achieved against a backdrop of climatic stress that limits yields, owing to shifts in pests and pathogens, precipitation, heat waves and other weather extremes (Bailey-Serres et al. 2019).

As the current world population is increasing at a faster pace and so many mouths need to feed, trying to attain food security will exert significant pressure on arable lands. The current climatic trend and population growth are to further extend the gap between food demand and food production in the world. According to the predictions of FAO, agricultural productivity requires to be increased by 60% more in 2050 to feed the world population (Silva 2018; Bohn 2014). Future access to affordable and healthy food will be challenging, with malnutrition already affecting one out of three persons worldwide (Varshney et al. 2021a). Several studies have shown that global crop production needs to double by 2050 to meet the projected demands of the rising population, diet shifts, and increasing biofuel consumption. Boosting crop yields is a preferred solution to meet this goal of meeting the rising demands, rather than clearing more land for agriculture.

Globally, hunger levels remain alarmingly high (The World Bank 2022) and the number of people affected by hunger arrived to 828 million in 2021 with an increase of about 46 million since 2020 (FAO et al. 2022) indicating the acute food insecurity in near future. FAO predicts that crop yields will decline by 25% by 2050 if we do not adequately address climate change. Plant breeding and the seed sector can help to reduce global hunger (Europeanseed 2017). A world with zero hunger is possible only through a sustainable increase in food production and distribution and the elimination of poverty. Scientific, logistic, and humanitarian approaches must be employed simultaneously to ensure food security, starting with farmers and breeders and extending to policymakers and governments (Fiaz et al. 2021). At present when the availability of staple foods needs to be dramatically increased to meet the needs of a rising human population; abiotic stresses (drought, salinity, high temperature, cold) and climate changes have been established as severe threats to global crop production. Thus, increasing plant resistance to various abiotic stresses is one of the top-priority goals for the scientific community to meet the food security need (Choudhary et al. 2022).

Four key global crops maize, rice, wheat, and soybean that currently produce nearly two-thirds of global agricultural calories have increasing yields at the rate of 1.6%, 1.0%, 0.9%, and 1.3% per year, non-compounding rates, respectively, which is less than the 2.4% per year rate and is far below what is needed to meet projected demands in 2050 (Ray et al. 2013). However, climate change can dramatically reduce agricultural productivity and the improvement of cultivars with limited resources may be required for resolving the food security issues in the world. Farmers around the world have recently experienced significant crop losses due to severe heat and drought. Such extreme weather events and the need to feed a rapidly growing population have raised concerns for global food security. While plant breeding has been very successful and has delivered today's productive crop varieties, the current rate of genetic improvement in terms of improved yield and quality trait performance must be doubled to meet the projected future demands (Voss-Fels et al. 2019). Thus, acceleration of the breeding process and advancement of breeding technologies are needed to make plant breeding more responsive to constantly moving targets and sustain its role as the principal provider of food security (Lenaerts et al. 2019).

The current agricultural production system is facing the challenge of sustainably increasing grain quality and yield and enhancing resistance to biotic and abiotic stress under the intensifying pressure of climate change. Under present circumstances, conventional breeding techniques are not sufficient. Innovation in plant breeding is critical in managing agricultural challenges and achieving sustainable crop production. Novel plant breeding techniques, involving a series of developments from genome editing techniques to speed breeding and the integration of omics technology, offer relevant, versatile, cost-effective, and less time-consuming ways of achieving precision in plant breeding and to attain global food security (Fiaz et al. 2021).

9.5.1 Role of Plant Breeding for Enhancing Crop Productivity

Plant breeding is the art and science of changing the genetic make-up of plants to produce desired characteristics like improved yield, taste, biotic and abiotic stress resistance, etc. for the benefit of mankind. Crop varieties play an essential role in improving the performance of the global agricultural industry; therefore, breeders are seeking new sustainable, efficient, and cost-effective methods to produce new varieties (Goncharov and Kosolapov 2021). It was found that almost 90% of the increase in average cereal yields over the past 25 years can be attributed to innovations in plant breeding with the development of new varieties with enhanced productivity. Typically, plant breeding contributes 1.0–1.5% yield improvement per annum (ISTA 2022).

Previously, conventional plant breeding through cross- and self-pollination strategies played a major role in improving agricultural productivity. Heterosis breeding can increase yield by more than 20% (Joshi 2003). New plant breeding approaches like evolutionary plant breeding can develop populations that have the potential to produce higher yields and perform better than their local or improved counterparts in adverse climatic conditions and thus can be utilized in developing improved populations of neglected and underutilized crops for food security (Joshi et al. 2020a). Similarly, another plant breeding approach like speed breeding is also under investigation which greatly shortens generation time and accelerates breeding and research programs. Speed breeding can be used to achieve up to 6 generations per year for spring wheat (*Triticum aestivum*), durum wheat (*Triticum durum*), barley (*Hordeum vulgare*), chickpea (*Cicer arietinum*) and pea (*Pisum sativum*), and 4 generations for canola (*Brassica napus*), instead of 2–3 under normal glasshouse conditions (Watson et al. 2018). These approaches can help in achieving the balance between the improvement rate of crops and the growth rate of the population thus expected to ensure food security in near future. Moreover, careful deployment and scientifically informed regulation, new plant breeding technologies (NPBTs) such as genome editing and the adoption of genetically modified (GM) crops by smallholder farmers have led to higher yields, lower pesticide use, poverty reduction, and improved nutrition (Qaim 2016). Recent advancements in genetic engineering have revolutionized plant breeding and crop improvement. Biotechnology enables creating dramatic alterations on crops to withstand stress which is difficult to attain using conventional breeding approaches. The development of biotechnological approaches such as genetic engineering, genome editing, RNA-mediated gene silencing armored with next-generation sequencing, and genome mapping have paved the way for precise and faster genetic modifications of plants. Those tools are utilized in creating high-yielding better-adapted crop varieties that are resilient to climatic changes (Munaweera et al. 2022). Targeted and rapid assembly of beneficial alleles using optimized breeding strategies and precise genome editing techniques could deliver ideal crops for the future. The implementation of this knowledge in breeding strategies might accelerate the progress in obtaining high-yielding cultivars (Nadolska-Orczyk et al. 2017).

The world today relies on a small number of crops for food. Out of the most used 15 crops which provide 90% of the world's food energy intake, the four crops; rice, maize, wheat, and soybean are known to dominate the global food system (Vogel et al. 2019). In addition to those, potatoes, tomatoes, bananas, cassava, etc. also play a very important role in global food security in less productive developing regions of the world. It is also found that crops of temperate and sub-tropical zones are more prone to yield loss. From 1980 to 2015 the decline in global wheat and maize yields due to biotic stresses was found to be 20.6% and 39.3%, respectively (Ristaino et al. 2021; Daryanto et al. 2016). Drought stress alone is estimated to limit crop productivity by more than half the amount in the next 50 years (Castaño-Sánchez et al. 2020). When considering the impact of climate change on food security globally, climate change is a serious threat to global food security, sustainable development and poverty eradication. Genetic improvement of crops is considered one possible solution to the crisis (Joshi 2017a). Thus, the identification and efficient utilization of superior genes is crucial for crop improvement methods for ensuring global food security.

The current development of advanced biotechnology tools allows us to characterize the role of key genes in plant productivity. Scientists from the University of Cambridge and the University of Bordeaux have discovered the Phloem Unloading Modulator (PLM) gene that helps control the movement of nutrients throughout plants which could be modified to increase crop yields influencing the transport of sugars, proteins, and other key organic nutrients between different parts of the plant that could provide the key to boosting crop production (Yan et al. 2019). AaPEPC1 gene (from *Agave americana* into tobacco) overexpression enhanced proline biosynthesis, and improved salt and drought tolerance in the transgenic plants. Under salt and drought stress conditions, the dry weight of transgenic tobacco plants overexpressing AaPEPC1 was increased by up to 81.8% and 37.2%, respectively, in comparison with wild-type plants. This finding has opened a new door to the simultaneous improvement of photosynthesis and stress tolerance in plants in the context of climate change (Liu et al. 2021). Such innovations in plant genomics and biotechnology will surely contribute to global food security. Several plant features and traits, such as overall plant architecture, leaf structure and morphological features, vascular architecture and flowering time are important determinants of photosynthetic efficiency and hence the overall performance of crop plants. The optimization of such developmental traits thus has great potential to increase biomass and crop yield (Mathan et al. 2016). The integration of genetic resources and transformative technologies, from genome editing to synthetic biology like improving metabolic pathways, and photosynthesis pathways, are necessary to capture traits could increase global food security and reduce the effects of agriculture on the environment (Bailey-Serres et al. 2019).

9.5.2 Role of Biotech in Improvement of Crops for Food Security

Conventional breeding has been transformed into molecular breeding, which then took the shape of genomics-assisted breeding with the aid of biotechnology. This advancement in plant breeding is precise and robust in developing new lines with enhanced agronomic as well as climate-resilient traits. Biotech crops are plants with DNA that have been modified through genetic engineering technology to introduce new characteristics to the plant which are not naturally present. Genetic engineering technique aims at developing biotech crops that could contribute to higher crop yields, lower use of chemical fertilizers and pesticides, better crop resilience to climate stress, reduced postharvest losses, and more nutritious foods (Qaim 2020). Farmers who have adopted genetically modified crops (GMCs) as a means of crop production have realized an approximately 22% increase in crop yield while pesticide use has been reduced significantly and farm income increased (WorldAtlas 2017). According to FAO (2015), 20–50% of yield losses worldwide are due to different biotic stresses or crop diseases. The other studies show that extreme heat and frequent droughts have resulted in about 10% reduction in the yield of cereal crops throughout the world from 1964 to 2007, and hence, the damage had been 8–11% more in developed than developing countries (Lesk et al. 2016). In 2019, the 24th year of commercialization of biotech crops, 190.4 million hectares of biotech crops were planted by up to 17 million farmers in 29 countries with an approximately ~112-fold increase from 1996 to 2019 (ISAAA 2020). Thus, biotech crops are considered the fastest adopted crop technology in the history of modern agriculture with global economic gains of US$224.9 billion from 1996–2018 improving the socio-economic condition of 17 million farmers worldwide (ISAAA 2020). According to ISAAA (2020), aside from the economic benefits, biotech crops also contributed significantly to food security, sustainable development, and climate change mitigation from 1996 to 2018 by increasing crop productivity by 822 million tons, conserving biodiversity by saving 231 million hectares of land, providing a safer environment by saving 776 million kg of pesticides from being released into the environment and reducing CO_2 emissions by 23 billion kg, equivalent to taking 15.3 million cars off the road for 1 year (2018). Thus, the development of new crop varieties with the help of genomics and biotechnology can significantly contribute to ensuring food security, environmental security and economic security, globally.

Even though more than 20 years of research and commercial applications suggest that GMOs are not riskier than conventionally bred crops (Greenpeace 2015), the argument continues to be widespread concerns about the possible negative health and environmental consequences. GM crops could contribute to food production increases and higher food availability, especially at a country level, however, not necessarily to food security (Przezbórska-Skobiej and Siemiński 2020) because of poor social and regulatory acceptance by several developed countries concerning its health risk concerns. Thus, each country needs to analyze the conditions and incorporate strategies with improved policies on agricultural development for better food security (Pachapur et al. 2020). Before a GM crop is approved for commercial use, it must pass rigorous safety and risk assessment procedures but states introducing and developing the cultivation or import of GM products must take control over their safety and security. Although there are many technical challenges to overcome, the biggest potential obstacles to the adoption of genome-editing tools in agriculture are public acceptance of the technology and government regulatory policies (Hua et al. 2019).

9.5.2.1 Breeding Crops Using Plant Transformation for Food Security

Plant transformation is one of the core techniques in plant biotechnology used to introduce desirable traits into an existing genome while preserving the genetic identity of the germplasm. *Agrobacterium*-mediated gene transformation is preferred over other techniques like electroporation, or gene gun (particle bombardment) methods because of its simple operation, the capacity of the transfer of larger DNA fragments in size, and reproducibility (Krenek et al. 2015). Using several techniques, transgenic crops are designed to increase their production, increase the net profit per hectare, have easy crop management, less labor requirement, and ability to use safer management practices. The transformation system has been used in crop improvements by combining with several other techniques such as RNA interference (RNAi) and clustered regularly interspaced short palindromic repeats (CRISPR) genome editing (Hayta et al. 2021; Che et al. 2018). Successful genetic transformations have been reported on rice (*Oryza sativa*), wheat (*Triticum aestivum*), maize (*Zea mays*), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), and several other crops using optimized tissue culture techniques (Ishida et al. 2007; Zhao et al. 2000; Munaweera et al. 2022) which has shown improvements in the crop yield in those crops through transformation. Transgenic rice expressing

Capsicum annum methionine sulfoxide reductase B2 (*CaMsrB2*) gene has been developed which has shown drought tolerance at the reproductive stage (Dhungana et al. 2015).

The introduction of a gene conferring ability into rice through transformation to increase the biosynthesis of an iron chelator in rice has also resulted in improvement in yield and growth under low iron availability conditions (Takahashi et al. 2001). The transformation technique has been successfully used to manipulate the brassinosteroid levels of the rice plant, resulting in an enhancement in the crop yield (Datta 2013). In terms of resistance to biotic stresses, genetically modified rice lines have been designed incorporating the *Bt* gene from *Bacillus thuringiensis* in several countries (Wang et al. 2018b). Results indicated the ability of genetic improvement in minimizing losses due to lepidopteran pests in Asia (High et al. 2004), high tolerance against rice leaffolder in China field trials (Chen et al. 2011), insect resistance in Pakistan and Mediterranean regions (Rahman et al. 2007). And the potential effect of Bt proteins against humans, and other animals including non-targets are demonstrated to be negligible (Genetic Literacy Project 2022). Among the large array of isolated Bt genes, CryIA(a) and CryIA(c) proteins are the most used in developing transgenic plants resistant to lepidoptera. After successful results of the cotton plant, *cry* genes have been incorporated in several other crops such as maize, rice, soybean, chickpea, and tomato to develop resistance against lepidopteron insect pests (Perlak et al. 1991; ISAAA 2020). Gram-negative bacteria such as *Xanthomonas oryzae* pv. *oryzae* (Xoo) and *Xanthomonas oryzae* pv. *oryzicola* (Xoc) are considered to affect worldwide rice production by causing bacterial blight and bacterial leaf streak.

The dehydration-responsive element binding (DREB) gene is one of the transcription factor genes investigated for improving water stress and the DREB1A gene was placed under the control of a stress-inducible promoter from the *rd29A* gene and inserted via biolistic transformation into bread wheat (Izydorczyk et al. 2018; Pellegrineschi et al. 2004). Even though so far, a significant yield improvement was not observed in the transgenic wheat plants, they are known to demonstrate a considerable adaptation to water stress conditions when compared to controls (Bansal et al. 2021). It has been reported that salt-tolerant plants also often tolerate other stresses including chilling, freezing heat, and drought and such high-performing genetically modified wheat plants have been developed around the world (Tadesse et al. 2019). The strains have been improved with nitrogen-fixing characteristics and the roots of wheat crops have been induced to form nodular structures as a step enabling non-leguminous plants to fix nitrogen in the soil (Li et al. 2020).

The genetically modified “MON87460” transgenic maize is a popular variety against drought. This includes the expression of cold shock Protein B to maintain the cellular functions under water stress conditions, preserving the RNA stability and translation (Sammons et al. 2014). This is already approved in more than 13 countries including European Union, the United States and Japan due to its 20% increased yields under water-stressed conditions (Ortiz et al. 2014). Maize homologs to the *Arabidopsis* Neurofibromatosis (NFB1) that confers resistance to drought have been used to engineer elite maize with enhanced adaptation to drought. The improved maize displayed reduced wilting, and maintenance of photosynthesis with a 50% increase in grain yield in drought conditions (Nelson et al. 2007).

Genetically modified soybean line transformed with *rd29A* showed overexpression of *AtDREB1A* gene and was found to enhance drought tolerance in soybean while increasing plant photosynthetic rate, plant chlorophyll content, and a higher stomatal conductance (Polizel et al. 2011). Several soybean varieties are currently commercialized and Roundup-ready (RR) crops were designed to tolerate the herbicide, glyphosate, through the expression of the *5-enolpyruvylshikimate-3-phosphate synthase* (*EPSPS*) gene from *Agrobacterium* spp. strain CP4 (ISAAA 2020). The soybean Bt lines are approved for commercialization in Brazil producing more than 114-million-ton in 2019 (Bel et al. 2017). Thus, the development of such varieties has significantly contributed to global food security by increasing yield under adverse stress conditions.

Abscisic acid (ABA) is involved in several metabolic pathways that play role in drought, salinity, and cold tolerance the plant (Xiong 2007). ABA and different abiotic stresses are known to induce the *H. vulgare* abundant protein 1 (HVA1) and the overexpression of HVA1 in different cereal plants was found to improve tolerance against different abiotic stresses (Nguyen and Sticklen 2013) without compromising the grain yield. Similarly, overexpression of HvSNAC1, a stress-responsive transcription factor, improves drought tolerance without any reduction in the plant's yield (Visioni et al. 2019). Several such mechanisms underlying stress-related gene expression have been evaluated and are known to have a major impact on the improvement of barley (*H. vulgare*) productivity with the increasing changes in climatic conditions (Gürel et al. 2016).

The tuber-specific gene *AmA1* is associated with increased protein content in potatoes (Hameed et al. 2018). Transgenic potato tubers with this gene contained more than a 60% protein than that of controls (Chakraborty et al. 2010), contributing to nutritional food security. Transformations have been done using *cry1Ac9* and *cry9Aa2* genes against several insect pests and such Bt-based transgenic approaches are considered highly successful practices in potato crops for increasing yield under biotic stress conditions (Meiyalaghan et al. 2006). Potato transformation experiments have shown that controlling biotic and abiotic stress can increase potato production for meeting global food demands. Overexpression of *Musa acuminate* plasma membrane intrinsic protein gene 1;1 (MaPIP1;1) in bananas has improved tolerance to numerous stressors. Various transcription factor genes, such as *MaERF14, MaDREB1G, MaMYB1R1, MaERF1/39, MabZIP53, and MaMYB22*, with similar expression patterns to MaPIP1;1 under salt or cold stress, have been identified which contributed for the development of stress resistance in banana (Sreedharan et al. 2013) and enhanced yield and quality.

9.5.2.2 Breeding Crops Using Next-Generation Sequencing for Food Security

Analysis of whole genomes is performed in next-generation sequencing (NGS) while allow to determine the genetic basis of important phenotypic differences and novel useful variations. Genomes of several important crops have been sequenced including rice (*Oryza sativa*), chickpea (*Cicer arietinum*), soybean (*Glycine max*), pigeon pea (*Cajanus cajan*), foxtail millet (*Setarica italica*), pearl millet (*Pennisetum glaucum*), etc., identifying their genotype-phenotype relationships (Li et al. 2015; Varshney et al. 2019). Several other plant genomes have been sequenced including wheat (*Triticum aestivum*) (Appels et al. 2018), and rye (*Secale cereale*) (Li et al. 2021). Re-sequencing of plant genomes and transcriptomes is aided by NGS techniques and the information has been used to create new, modified reference genome maps on crops such as rice (Sasaki 2005), maize (Schnable et al. 2009), and soybean (Schmutz et al. 2010). Information obtained from such studies can contribute to improving crops for their yield, quality and other agronomic traits with precision. The development of next-generation sequencing has accelerated the quantitative trait loci (QTL) mapping and is successfully used in the identification of genes conferring defense mechanisms against biotic and abiotic stresses (Vlk and Řepková 2017). Sequencing techniques have been successfully employed in the identification of effector proteins that could be useful in breeding wheat varieties resistant to pathogens, *Puccinia striiformis* (Garnica et al. 2013) and increasing productivity.

Similarly, drought-tolerant genes have been revealed in *Populus* sp. (poplar) and *Trifolium pratense* (red clover) plants using NGS. Illumina sequencing has been used for the identification of copper tolerance genes in plants (Ando et al. 2012), herbicide-resistant genes in *Lolium rigidum* (Gaines et al. 2014), and identification of transcription factor family of soybean, during development and dehydration stress (Le et al. 2011). Incorporation of such biotic and abiotic stress resistant/tolerant genes in staple food crops can significantly increase food production in drought conditions with the advent of new genomics-based biotechnological approaches.

9.5.2.3 Breeding Crops Using Omics Technologies for Food Security

Genomics technology has made it possible to sequence all the genomes of different plants and animals and has successfully identified several candidate genes playing role in different growth and development of plants and animals. After the development of next-generation sequencing, several advanced technologies have been developed like genomics, transcriptomics, proteomics, metabolomics, etc. which have contributed to identify several QTLs, candidate genes, transcription factors, protein-coding sequences and metabolites in model crops as well as in their related species.

Transcriptomics is one of the most popular omics (study of the whole) technologies used widely in crop improvement these days. Transcriptomics studies the functional genome of living organisms including a total number of transcripts, their abundance in a specific cell, and post-transcriptional modifications. With the development of new techniques, RNA sequencing and transcriptome level profiling have been used to understand the molecular basis of abiotic stress responses of maize such as salinity, heat, drought, etc. (Qian et al. 2019). Several regulatory regions in transcripts involved in plant stress responses are identified using transcriptome data (Juntawong et al. 2014). The combination of published RNA sequence data, also known as transcriptome, and meta-QTL analysis has been used for the identification of candidate genes involved in kernel row number in maize (Taheri et al. 2018) and novel salt tolerance genes in soybean (Qi et al. 2014) for improved yield in abiotic stress conditions. In hybrid rice, the differentially expressed genes (DEGs) involved in metabolic activities, regulation of signal transduction, and photosynthesis in response to heat stress have been identified using these techniques. This baseline information could be successfully used in crop improvement programs afterward for improving yield in those crops under adverse climatic stresses. Root transcriptome analysis at different growth stages of the plant has revealed the molecular mechanism of root growth and development of maize (Zhang et al. 2015).

Transcriptome analysis has been used to reveal nearly 130 drought-responsive genes in tomatoes and transcription factors regulating stress-responsive genes have also been identified (Kim et al. 2015). Tomato's resistance to chilling conditions has been revealed using Brassinosteroids (BS) mediated regulation (Xia et al. 2021). Revealing enhanced tolerance to water deficit, salt stress, and chilling conditions using the transcription factor CBF driven by ABTC1 is considered a great finding as results were not affecting plant growth and yield under normal growing conditions (Foolad and Panthee 2012).

Proteomics, the study of protein profiles, of the plant could reflect the currently occurring processes in the biosystem and could be used for crop improvement with much more precision. For example, protein profiling carried out on soybean has revealed that more than 141 proteins were significantly upregulated in salinity conditions, and at moderate salinity levels, embryo proteins were found to be protected from degradation. However, in high salinity conditions, the protection seemed to be reduced (Varshney et al. 2021b). A thorough analysis of these pathways could be important for improving plants' resistance to stress conditions. Similarly in *Verticillium dahliae* inoculated cotton, two proteins 1-aminocyclopropane-1-carboxylate oxidase (ethylene biosynthesis) and ethylene-responsive transcription factor (ERF060), were found in high amounts and found to be involved in the defense response of the plant against stress conditions. That information can be utilized in improving crops for stress tolerance.

9.5.2.4 Breeding Crops Using Marker-Assisted Selection for Food Security

Marker-assisted selection (MAS) has been utilized for the introgression of several candidate QTLs into elite cultivars successfully to improve crops such as maize, rice, wheat, cowpea, etc. (Kumar et al. 2019). Molecular markers closely associated with major QTLs in different crops are used for identifying the crop species with those QTLs and genotyping them for crop improvement. The pleiotropic effect of SCM2 QTL was found to enhance the number of spikelets per tiller in rice (Kumar et al. 2017). Identification of the gene *SUBMERGENCE 1* (*SUB1*), which is a major QTL conferring tolerance to submergence in rice, is one of the most successful examples of QTL utilization for increasing rice grain yield under submerged conditions (Nair and Shylaraj 2021). Genome-wide studies have identified some submergence-related genes *Sub1A* and *SNORKEL* (Hattori et al. 2009) of rice and *Rhg1* in soybean which confers resistance to cyst nematode (Cook et al. 2012). These identified genes can be utilized to further improve the crops for better productivity under biotic and abiotic stress conditions.

Potassium homeostasis in plants is regulated by SKC1 in chromosome 1, providing it the salt-tolerant ability, while acting as a molecular marker suitable for selecting salt-tolerant cultivars (Luo et al. 2019) for saline conditions. When compared with other crops, maize is considered a crop relatively sensitive to flooding, and interestingly there are several maize relatives such as *Zea nicaraguensis*, and *Z. luxurians* with a higher flood resistance. Finding out marker genes for salt and flood tolerance can identify maize varieties suitable for flood-affected and saline areas and increase food production. Multiple QTL-related studies were carried out on these crops to locate the flood and salinity resistant genes (Mustroph 2018).

Several markers associated with QTLs which govern several abiotic stress tolerance characteristics such as drought tolerance, submergence tolerance (SUB1), and salinity tolerance in barley (Singh et al. 2013) have been identified for improving barley productivity. Molecular markers have been developed for major resistance genes and QTLs against many pathogens in barley such as rust and powdery mildew for increasing yield under biotic stress conditions (Perovic et al. 2019). In tomatoes, more than 100 loci responsible for the resistance to 30 major diseases have been mapped and molecular markers associated with those traits have been reported (Lapidot et al. 2015).

9.5.2.5 Breeding Crops Using Gene Silencing for Food Security

The RNA interference (RNAi) technique, considerably old, used in the creation of the “Flavr Savr®” tomato, is now applied on several crops. Currently, endeavours are taken in developing climate-ready crops, resistance to several abiotic factors such as salinity, drought, temperature, and biotic stresses such as insect and pest spread (Borges and Martienssen 2015) so that already popular crops and their varieties can be further improved for yield, quality and other agronomic traits. RNAi silencing of *RACK1* gene expression in rice has been utilized for improving drought tolerance and the resulting plants have shown higher growth even under water stress conditions (Li et al. 2009). RNAi technology applied in the putative V-ATPaseA coding region in maize has shown corn rootworm pest resistance making the plant biotic stress resistance with improved yield (Shaffer 2020). These innovations have a significant impact on improving the crop yield in stress conditions although further research is necessary.

RNA is the transcribed copies of functional regions of DNA present in an organism's genome which produces protein translation. There is another class of RNA called micro-RNA (miRNA) which plays the role as a key regulator in plant growth, development, and metabolism, especially in root development architecture targeting auxin response transcription factors, regulation of fruit growth, development of leaves, apical dominance, and production of plant biomass (Zhang and Wang 2015). miRNA technology in plant biotechnology is an innovative approach for gene silencing. When miRNA is inserted in a plant cell, it can mimic the endogenous RNA and shows translational inhibition of certain genes which may be useful in many cases (Wang 2009). Several miRNAs such as miR319, miR393a, and miR5144, have been recognized in numerous crops including wheat (Gupta and Huang 2014), rice (Mittal et al. 2016) for salinity stress-tolerance and several other miRNAs were found to be involved in plant drought-related mechanisms. For example, miR319 is known to be linked with salt stress tolerance, drought tolerance, and the tolerance to chilling conditions in rice (Sircaik et al. 2021) which can be optimized to improve crops to resistant against several stress conditions. Therefore, the single attempt at using the miRNA technique seems to be enough to improve crops against several stress conditions thus improving crop productivity.

Both abiotic and biotic stress-related plant responses are regulated by using WRKY transcription factors superfamily genes in soybean. Virus-induced gene silencing technique has been used to silence 64 soybean WRKY transcription factors. Silencing of GmWRKY36, GmWRKY40, and GmWRKY45 genes was highly related to plant stress resistance (Pandey et al. 2011). Such genes can be incorporated into cultivated soybean varieties for developing stress resistance varieties for increasing yield even under stress conditions due to climate change. RNAi approach was also used in potatoes for increasing beta-carotene and lutein content by silencing the *bch* gene (Van Eck et al. 2007) for ensuring nutritional security. Flavr Savr™ tomato, which was created using antisense RNA technology to increase the shelf life, can be considered the first transgenic variety approved by FDA (USA) and commercialized in 1994 (Bruening and Lyons 2000). However, with the introduction of several other transgenic products and biosafety concerns, it was withdrawn from the market in 1999.

9.5.2.6 Breeding Crops Using Genome Editing Technology for Food Security

Genome editing is predicted to be a powerful addition to the fight against hunger and poverty. The global community should seize this opportunity by developing conducive regulatory frameworks and support mechanisms (Zaidi et al. 2019). Genome editing tools are a few of the most used techniques now to overcome the adverse effects of climate change and to compensate for the increased demand for food in the future. It is a novel, highly used technique and, a fast crop improvement method (Ahmar et al. 2020). Genome editing technologies have an advantage over other older transgenic techniques or plant transformation techniques in that the genome of any crop can be easily modified without introgression of the transgene (a gene from other unrelated organisms) which may have negative impacts and thus, can be taken as an alternative for overcoming the biosafety concerns of transgenic crops or GMOs. Engineered homing endonucleases/meganucleases, Zinc Finger Nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR-associated (Cas) 9 are some highlighted gene-editing tools in plant research recently (Bilichak et al. 2020).

ZFN was commonly used for several genome modifications of plants such as *Arabidopsis thaliana*, tobacco (*Nicotiana tabacum*), and maize (*Zea mays*) (Petolino et al. 2010). In *Brassica napus*, activation of transcriptional machinery of the b-ketoacyl-ACP Synthase II gene (Gupta et al. 2012), edition of herbicide transmission-related *DCL* gene, and *PAT* gene of soybean and maize (Shukla et al. 2009) are a few of the instances of effective use of ZFN. This technique has allowed precise integration of the transgene to the target site with no disruption to the gene coding elements while segregating together in meiosis as a single locus. Therefore, it has also facilitated obtaining the progeny with all added traits. ZFN has been used to edit maize gene *ZMIPK1*, improving it with herbicide tolerance characteristics (Shaffer 2020; Liu et al. 2020). The development of herbicide tolerance maize can reduce labor costs and farmers will be more interested to cultivate such varieties for stable yield on a commercial scale.

Successful utilization of TALENs was performed in several crops including soybean, barley, wheat, and tomato (Becker and Boch 2021). TALENs have been used to target three TaMLO homologous alleles in making the resistant to powdery mildew. In addition, the nutrition profiles of several crops have been modified with the use of TALENs. Soybeans with high oleic acid content and tubers containing reduced sugars are some examples developed using TALENs (Becker and Boch 2021).

CRISPRCas9–mediated gene knockout is widely used for a variety of applications in crop improvement—for example, high-yield rice, disease-resistant bread wheat, and flavor-enhanced tomato (Zaidi et al. 2019). CRISPR has been developed as a versatile genome editing tool that can be applied for several applications due to its ability to perform on multiple target sites, efficacy, simplicity, and low cost compared to ZFN and TALENs (Bortesi and Fischer 2015). Research reports from 2014 to 2017 suggest that CRISPR-mediated genome editing has been applied to several fruits and crop genomes, and rice (*Oryza sativa*) was the most studied and nearly 40% of them were successful with an improvement in yield (Cong et al. 2013). Improvement of rice seedling salt tolerance using transcription factor SST, cold tolerance using editing the yield-related genes (*OsPIN5b* and *GS3*), and the cold stress-related gene (*OsMYB30*) are recent uses of the CRISPR technique (Sircaik et al. 2021). Modification of the gene *CsLOB1* has resulted in plants' resistance to the severe disease called "citrus canker". Many genomes including rice, maize, wheat, and soybean have been modified using CRISPR in making plant genomes "climate-ready" or climate change resilient. Such crops have improved traits for yield, quality and other agronomic traits. The ability of this technique to avoid tedious screening and its less tricky nature has advantages over other methods. However, compared with its use on animal cells, the success rate of plant cells is considered low (Jia et al. 2016) and is still under experimentation.

CRISPR has been used in conferring resistance to rice blast in both seedling and tillering stages by silencing the ERF transcription factor gene *OsERF922* (Perlak et al. 1991). Other than that, CRISPR has been successfully used to knock out the *Os8n3* or the *xa1* gene in rice which makes it resistant to *Xanthomonas oryzae* (xoo) infection (Yang et al. 2006). Thus, such advancements in genomic tools have contributed to stable and higher yield of rice varieties under biotic and abiotic stresses ensuring food security in stress-prone regions. CRISPR-mediated knockdown of *gna1a*, *dep1*, and *gs3* genes are found to be involved in the development of climate-ready rice (Li et al. 2016). The GRAIN NUMBER 1a (Gn1a) allele in the Indian rice Habataki has a mutation in the gene encoding cytokinin (CK) oxidase/dehydrogenase; the (OsCKX2) catalyzing the degradation of CK. The resulting accumulation of CK in the inflorescence is found to increase the grain production of the rice plant (Wang et al. 2020; Joshi et al. 2018).

Similarly, the dense and erect panicle gene (*dep1*) was also found associated with increasing yield. A mutation in grain Size (GS3), the gene which is co-located with a major QTL for grain characteristics was also found to result in long grains and an increase in grain weight. CRISPR edition of OsLOGL5 coding sequence of rice cytokinin activation enzyme-like gene that affects root growth, tiller number, and yield has successfully resulted in an increase in grain yield under drought conditions (Li et al. 2016). Similarly, CRISPR/Cas9 system was found highly efficient for the knockout of negative regulating loci, e.g., GS3, DEP1, GS5, GW2, Gnla, IPA1 and TGW6, which control grain yield in *O. sativa* L., resulted in a significantly improved grain yield in mutant plants (Li et al. 2016). TALEN and CRISPR-mediated genome editing was applied in wheat for manipulation of the transgene *Pinellia pedatisecta* agglutinin (PPA) for improvement of aphid resistance, and powdery mildew resistance by manipulating the target gene TaMLO which can contribute to improve wheat yield under biotic stress conditions (Duan et al. 2018). CRISPR/Cas9-based genome editing of wheat for achieving powdery mildew resistance has shown reductions in fungal structures and microcolonies in edited lines (Wang et al. 2018a). CRISPR-mediated editing of the gene *TaGASR7* for the improvement of grain length and weight (Zhang et al. 2016), and phytoene desaturase (PDS) gene for the improvement of plant chlorophyll synthesis (Cram et al. 2019) are a few of the successful modifications in the world for wheat productivity improvement. Further research is necessary for wheat for developing varieties with improved performance.

CRISPR/Cas9-mediated editing of MORC1, a defense-related gene previously identified in *Arabidopsis thaliana*, has been used to increase the resistance to both *Blumeria graminis* f. sp. *Hordei*; the cause of barley powdery mildew, and *Fusarium graminearum* in barley. Genes responsible for several abiotic and biotic stress resistances have been identified in the genome of wild species of barley (Galli et al.

2022) paving the pathway to several improvements in a barley crop. Identification of such biotic and abiotic stress resistance genes can be useful in developing the varieties for improved yield in barley and other related species for food security. In addition, a semi-dwarf banana variety has been developed by generating knockouts of genes for the biosynthesis of gibberellins using CRISPR/Cas 9 technology, which can withstand lodging conditions that occur due to intense winds, typhoons, and storms (Xu et al. 2021). Studies showed that CRISPR/Cas9 editing tools have been efficiently utilized in several horticultural crops including petunia, citrus, grape, and apple for gene mutation, repression, activation, and epigenome editing (Munaweera et al. 2022).

Following rice and maize, cassava is considered the third largest source of dietary carbohydrates, especially starch, in the tropics. It is one of the most drought-tolerant crops, able to thrive in even arid conditions and ensure food security in those regions. Gene editing has been used to combat the brown streak virus, which can cause yield losses of up to 70% in cassava (Munaweera et al. 2022). Potyviridae viruses require eIF4E isoforms encoded by the cassava genome for the infection, similar to rice. The simultaneous targeting of two such eiF4E genes, *ncbp1* and *ncbp2*, using CRISPR/ Cas9 has improved plant resistance in cassava (Gomez et al. 2019). These findings can contribute to increasing the yield of cassava under biotic and abiotic stress conditions in food insecure countries.

9.5.3 Breeding Neglected and Underutilized crops for Food Security

Neglected and underutilized species (NUS) are those crop species that are not included in formal research, education, and development. These crops are known for their high potential for food and nutritional security, and high adaptability to changing climates (Joshi et al. 2020b). Several underexploited crops and local landraces are the major sources of food security in high hills and marginal lands. Some of them are defined as future smart food crops based on their nutritional value (Joshi et al., 2019). Most of the hybrid and genetically modified crops can't perform well under poor management as is done by remote poor farmers in marginal lands across the world. There are several traditional crops that play an important role in household food security and livelihood needs of mountain communities, while at the same time safeguarding crop biodiversity for future generations (Gauchan et al. 2020). Thus, breeding in those crops for biotic and abiotic stress resistance thus increasing crop yield is a major option to ensure food security in less accessible remote areas worldwide. New plant breeding approaches like evolutionary plant breeding can be applied successfully in improving neglected and underutilized local landraces of crops and developing climate resilient crop populations which have an important role in ensuring food security in less productive regions of the world (Joshi et al. 2020a). Several field experiments have also been conducted in Nepal for identifying biotic and abiotic stress resistance/tolerance in local landraces which have an important role in rural food security. There are some local landraces of naked barley (*Hordeum vulgare*) (Karkee et al. 2022), finger millet (*Eleusine coracana*) (Gurung et al. 2020), mountain rice (*Oryza sativa*) (Ghimire et al. 2018), etc. which are resistant to disease with higher yield as compared to other improved varieties and have played a key role in ensuring food security in mountain regions of Nepal. There are several other crops that need breeders' attention for identification and improvement for meeting global food as well as nutritional demands. Taro (*Colocasia esculenta*) is one underutilized crop that has been identified as a potential source of antioxidants and to mitigate chronic malnutrition and hunger (Munaweera et al. 2022). Recently genomic sequencing of Taro has revealed that 17,097 genes could potentially be functional proteins. Meanwhile, 26 genes were associated with the starch biosynthetic pathway followed by validation through RT-PCR analysis. Since Taro is distributed worldwide, it needs much attention towards modern biotechnology techniques to become one of the "climate-ready crops" (Matthews and Ghanem 2021; Kapoor et al. 2022).

Similarly, crops such as cassava, cowpea, and yams with a relatively low commercial potential are considered to grow in most developing countries to meet the food requirement. Despite their importance, they are less addressed in biotechnological efforts. That could be one of the reasons for less usage of GM crops because the crop of the target in research is a non-target in multiple regions of the world (Munaweera et al. 2022). Yam (*Dioscorea* spp.) is another good example of a neglected but important crop for food security. It is the staple food crop in many African countries such as Ghana and is also considered to have several nutritional properties along with medicinal importance (Epping and Laibach 2020). However, utilization of yams in crop improvement is negligible as the research work on yams is mostly limited to its characterization based on phenotypic and molecular markers. Efforts can be targeted to improve their use as there are some yams with high medicinal properties but are not edible (Munaweera et al. 2022). They could be modified to contain no toxins, so more germplasm becomes available for utilization and major food crop improvement. A similar condition remains true for the crop *Lathyrus*, which is a protein-rich legume, known to use after soaking overnight to clear the toxins contained in split seeds. Identification of genes for removing toxins and utilizing them as minor food crops can also pave way for ensuring food security in marginal areas.

As marker assistance and genomics continue to speed up conventional breeding, agricultural researchers should extend attention to the ignored crops often called "orphan crops". Orphan crops include sorghum, millet, taro, faba bean, etc. all of which are important food sources for many people in food-insecure regions across the world. Marker assistance and genomics made it easier to achieve quick yield improvements in these less-studied crops by increasing the pace of breeding programs and by understanding the gene combinations that have already led to yield gains in more intensely studied crops such as maize, rice, and wheat. Breeders can then select these advantageous gene combinations in the orphan crops to achieve yield gains and can be utilized for securing food demand (World Resources Institute 2014).

Recent advances in genome editing allow the alteration of endogenous genes to improve traits in crops without transferring transgenes across species boundaries. In particular, CRISPR-Cas has emerged as one of the foremost systems with which to edit the crop genome, with rapidly increasing agricultural applications in major cereals such as rice, wheat, and maize and other food security crops such as banana and cassava (Bull et al. 2018). Because of its low cost, genome editing can also be used to improve orphan crops such as local fruits, vegetables, and staple crops that can play an important role in healthy diets (Zaidi et al. 2019). Further research in the omics and gene editing field is still needed to identify useful candidate genes and QTLs in different crops so that they can be utilized to accelerate the rate of crop improvement in less time and ensure global food security.

9.6 Current Challenges and Prospects

There is an urgency to double the crop production to feed the ever-rising human population which is projected to reach 10 billion by 2057. With the existing availability of food resources and crop varieties, the current food production system would not be sufficient to reach future food demand. Thus, urgent actions need to be executed to improve the global food system. Proper identification of the remaining challenges in crop improvement and the introduction of novel plant breeding techniques for improving crop yield and other agronomic traits is mandatory. Cereal, fruit, vegetable, legume and several underutilized crops also need attention towards genomic assisted breeding to combat abiotic and biotic stresses so that global food demand can be met. Genomic-assisted breeding techniques have been directed towards major cereal crops, however, the accomplishment of sustainable development goals (SDG) by 2030 needs immense production of staple food crops and other minor food crops to ensure global food security. Realizing the potential of marker-assisted and genomics-assisted breeding of major food crops as well as of orphan crops, plant breeders will require substantially more and consistent investment in research and development. Thus, it is important to increase and stabilize crop breeding programs budget by the government and private sectors in near future by leveraging technologies through a public-private partnership. The research attention should also be given to neglected and orphan crops for ensuring food security worldwide. Breeders should not only focus on improving higher yielding traits but also on the health and environmentally advantageous traits like pesticide and herbicide resistance, improved photosynthesis rate and reduced toxins, etc.

9.7 Conclusion

Greater and more consistent crop production must be achieved against a backdrop of climatic stress that limits yields, owing to shifts in pests and pathogens, precipitation, heat waves and other weather extremes to feed the global population of 9.6

billion by 2050 and 10 billion by 2057 for which above 70% more food must be increased. Crop improvement through genetic manipulation is the only viable option to meet the global food and nutrition demands in addition to minimizing the other environmental problems. Site-specific staple crops or varieties need to be developed not only focusing on only a few major crops but also focusing on underexploited/local crop diversification which has an important role in ensuring site-specific food and nutrition security. However, the conventional breeding system is considered as not effective due to consuming a long time (6–12 years) and tedious to develop new varieties.

Therefore, multiple strategies are needed to accelerate crop performance using advanced biotechnological tools such as transformations, next-generation sequencing, omics technologies, marker-assisted selections and a novel genome editing technology for accelerated improvement of food crops for getting higher yield as demanded by the growing population. Several genes have been identified and utilized in different crops like rice, wheat, maize, soybean, tomato, banana, etc. which have a major role in food security, thus those crops must be improved to cope with the adverse impact of climate change, biotic and abiotic stresses so that food security can be ensured. Crop improvement should not only be limited to major stable food crops, breeders must also study the potentiality of underutilized crops which have a small but significant role in meeting global food security. Breeding of wide adaptability varieties of only a few crops needs to reorient to develop site-specific and dynamic populations.

For the ornamental and horticultural crops and plants propagated vegetatively, plant tissue culture plays a great role to improve crops. More recently, molecular breeding and genetic engineering systems have been used successfully in many crop species. The genetically engineering system using cisgenic technology would be a good option for the upcoming breeding system, where genetic material from the same species or a species that is naturally bred with the host is used. Among different technologies adopted for crop improvement, the CRISPR/Cas9 system can be adopted and modified for precisely editing, regulating, and monitoring an individual gene in plants and animals as well as microbes for a wide range of purposes, including improvement of crop growth, development and further yield and quality as well as tolerance to various environmental biotic and abiotic stresses would be the best option. However, it must be modified to make it more efficient, and robust with few off-target effects should be of priorities of these days.

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Chapter 10
Crop Breeding and Biotechnological Advances Towards Nutrition and Environment Security

Bal Krishna Joshi, Hari Kumar Shrestha, and Dipendra Kumar Ayer

10.1 Introduction

The concerns about nutrition security, human health and environment have gained substantial momentum, mainly due to rapid increases in global population and food insecurity. Historically, plant breeding remains key for improving crop yield, but their role on nutrition, environment and human health have not explored. Plant breeding can address the nutritional insecurity, human health problems and environmental degradation, by manipulation genetic makeup, creating new genotypes and adding different kinds of compounds including health-promoting bioactive compounds.

Nutrition is the major source of energy and building block for human life. Good quality of food i.e. nutrient rich food influences the quality of individual life, including the ability to maintain the body system for effective movement, work, and good physical appearance. Around 2.3 billion people in the world were moderately or severely food insecure in 2021 and 11.7% of the global population faced food insecurity at severe levels (FAO et al. 2022). The FAO et al. (2022) estimated that about 3.1 billion people are unable to afford a healthy diet that causes malnutrition. The number is 112 million more people compared to 2019. In addition, the Ukraine-Russia war will again increase this gap in food and nutrition security due to two of the biggest producers of agriculture and staple cereals globally.

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"Hidden hunger" (deficiency of micronutrients) is a global concern, where an estimated two billion people suffer from a chronic deficiency (or inadequate intake) of essential vitamins and minerals (micronutrients) in the daily diet (Muthayya et al. 2013). Worldwide, the most widespread micronutrient deficiencies are iron, zinc, iodine, and vitamins (vitamin A, folate (B9), and vitamin B12). Although distributed globally, over 98% of malnourished persons reside in developing countries, where particularly young children and women of reproductive age living in low-income countries are the most vulnerable to this "hidden hunger. Therefore, a good solution to this issue may be found effective if everyone in the society has access to safe and adequate food, which meets the energy requirements and ensure it functional adequacy of an organism. For improving the nutrition status, environment should also be in good condition.

Environment degradation is a major concern worldwide. Climate changes and the unwise applications of pesticides, and chemicals in agriculture have devastated the environment. Temperature is increasing each year (Fig. 10.1) and the world is experiencing adjustment difficulties. Unanticipated climate events include drought, extreme temperature, flood, storm, wildfire, etc. have hampered crop production significantly each year across the world (Razzaq et al. 2021). The extreme events of climate change have increased the loss of agricultural land and accelerated biotic and abiotic stresses (Raza et al. 2019). Thus the development of climate resilient varieties through crop improvement would be extremely beneficial to tackle such climate events as well as to improve the environment.

Pesticides are poisonous to almost all living beings and serious problem for each ecosystem. However, about, two million tons of pesticides are utilized annually worldwide and about 44% of farmers are poisoned by pesticides every year (Boedeker et al. 2020; Sharma et al. 2019). The best option to get rid of such a situation is resistance breeding through which crop varieties are developed with either

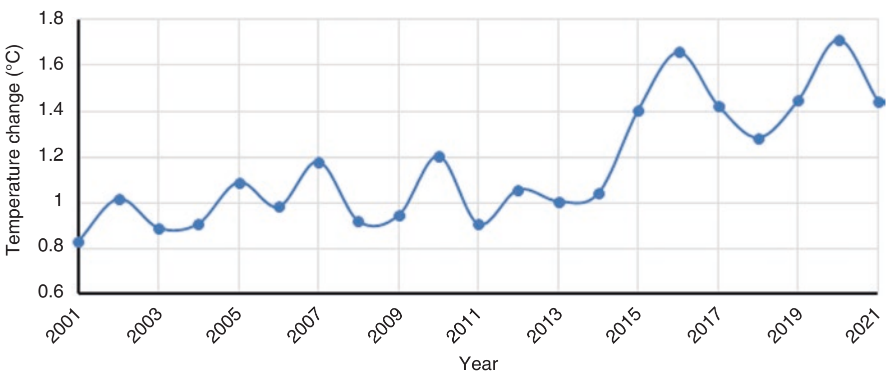

Fig. 10.1 The trend of annual changes in the world's temperature from 2001 to 2021. (Source: FAO (https://www.fao.org/faostat/en/#data/ET))

resistance or tolerance to any kind of stress. Therefore, crop improvement is the most important strategy for nutrition and environmental security along with the improved health system anywhere in the world.

10.2 Breeding for Nutrition Security and Human Health

Nutrition takes part in various catalytic and regulatory functions of the main metabolic process, including absorption, transportation, redux and biosynthesis of organic compounds, genetic information, etc. A deficiency in nutrition, including mineral and vitamins, disrupt these functions, thus leads to serious illness. Nutrition security builds on food security, emphasizing the co-existence of food insecurity and diet-related diseases and disparities (USDA 2022).

Malnutrition is a global health problem (Table 10.1). Therefore, the United Nations General Assembly session which was organized on 1 April 2016 also emphasized the importance of healthy diets and food systems for global human health. The period from 2016 through 2025 was announced as the UN Decade of Action on Nutrition. However, until now, the global agricultural research and development system has been designed only giving top priority to increasing grain yield and crop productivity, instead of focusing on increasing nutrition for the promotion of human health. Therefore, this system led to a gap in micronutrient deficiency in staple food crops, mainly rice, wheat, and maize; thereby increasing micronutrient malnutrition among consumers, particularly in developing countries. Currently, some nutrition-sensitive agriculture research and development activities are shifting from higher yield to nutrient-rich crops in sufficient quantity to fight against hidden hunger or micronutrient malnutrition, especially where their food source is cereals-based and micronutrient-poor (Yu and Tian 2017; Garg et al. 2018; Stangoulis and Knez 2022). Therefore, the purpose of this work was to examine the global scenario of malnutrition, major micronutrients and their key functions, and the main approaches associated with a long-term biofortification strategy to eliminate

Table 10.1 The global status of malnutrition and its impact on the economy

SN	Types of malnutrition	Affected people (%)	Age group
1	Hidden hunger	2 billion	All
2	Undernourished	820 million	All
3	Stunted	149 million (21.9%)	Children <5 yrs
4	Wasted	49.5 million (7.3%)	Children <5 yrs
5	Death	45%	Children <5 yrs
6	South Asian regions		
6.1	Stunted	31%	Children <5 yrs
6.2	Wasted	14.3%	Children <5 yrs
7	GDP losses in Asia & Africa	11%	
8	The cost associated with malnutrition	USD 3.5 trillion per year	

Source: GNR (2016, 2018, 2020), UNICEF et al. (2020)

malnutrition, concentrating on several kinds of cereal as the most popular staple food crops.

10.2.1 Conventional Plant Breeding

Conventional plant breeding (CPB) has been going on for hundreds of years and is still popular in developing new varieties with desirable traits in the offspring. Early generation farmers discovered that some crop plants could be artificially mated or cross-pollinated to increase yield. In the 20th century, the plant breeding system was further developed for the purposeful manipulation of quality traits in plants to create new varieties with a set of desired characteristics. The development of both the open-pollinated (OP) and hybrid varieties has dramatically increased the productivity and quality of various crop varieties for food, feed, fibers, and other industrial purposes.

Conventional plant breeding-based biofortification is a well-accepted method to improve the micronutrients, such as minerals (Fe, Se, Zn, Cu, Mg), vitamins (A, E, C) and essential amino acids (lysine, tryptophan) in crop varieties (Garg et al. 2018). In this system, parent lines containing high nutrients are crossed with recipient (target) lines over several generations to produce crop varieties with nutrients and agronomic traits (Garg et al. 2018). Using this technology, a good number of crops have been developed for fortification which harbor or be better able to uptake higher levels of micronutrients such as Fe, Se and Zn from the soil and then collect them in edible portions. For example, the world's first zinc enriched rice varieties (BRRIdhan 62, BRRIdhan 72 and BRRIdhan 64) developed by HarvestPlus were released in 2013 by Bangladesh Rice Research Institute (BRRI) that contains a maximum Zn content ranging from 20–22 ppm against the world average of 14–16 ppm in other varieties (Josh 2013; Garg et al. 2018). Similarly, crops like rice, maize, wheat, millets, lentil, groundnut, linseed, cauliflower, potato, sweet potato, etc. also can be increased their nutrient contents which are beneficial for improving health condition of human beings. It is the most sustainable and trustful approach to address the global micronutrients issue (Table 10.2). However, developing micronutrient enrich varieties is a time-consuming process, that can limit its effectiveness in micronutrient-deficient soil, limited due to the non-availability of enough genetic variation in the crossable gene pools or genetic exchange between closely related species (Garg et al. 2018; Kumar et al. 2019). In addition, it also lacks the modulation of target gene expression underlying the micronutrient accumulation. Therefore, modern plant breeding tools such as genetic engineering can be effectively and efficiently used to address these issues.

Table 10.2 Nutrition level improvement in different crops (OPVs+hybrids) through conventional breeding system

Crops	Nutrients	Baseline levels	Levels achieved	References
Rice	Protein	7–8%	>10%	Yadava et al. (2020)
	Iron	12 mg/kg	21 mg/kg	Gregorio et al. (2000)
	Zinc	12–16 ppm	>20 ppm	Yadava et al. (2020)
		14–16 ppm	>20 ppm	Josh (2013), Garg et al. (2018)
			40%	Josh (2013), Garg et al. (2018)
Maize	PVA	0.5–1.5 ppm	>5 ppm	Yadava et al. (2020)
	Lysine	1.5–2.0%	>2.5%	Yadava et al. (2020)
	Tryptophan	0.3–0.4%	>0.6%	Yadava et al. (2020)
Wheat	Protein	8–10%	>12%	Yadava et al. (2020)
	Iron	28–32 ppm	>38 ppm	Yadava et al. (2020)
	Zinc	30–32 ppm	>37 ppm	Yadava et al. (2020)
			30–40%	Thapa et al. (2022)
Pearl Millet	Iron	45–50 ppm	>70 ppm	Yadava et al. (2020)
	Zinc	30–35 ppm	>40 ppm	Yadava et al. (2020)
Finger Millet	Iron	25.0 ppm	>38 ppm	Yadava et al. (2020)
	Zinc	16.0 ppm	> 24 ppm	Yadava et al. (2020)
	Calcium	200 mg/100 g	>400 mg/100 g	Yadava et al. (2020)
Lentil	Iron	45–50 ppm	>62 ppm	Yadava et al. (2020)
	Zinc	35–40 ppm	>50 ppm	Yadava et al. (2020)
Groundnut	Oleic acid	45–52%	>70%	Yadava et al. (2020)
Linseed	Linoleic acid	20–25%	>58%	Yadava et al. (2020)
Cauliflower	PVA	Negligible	>8.0 ppm	Yadava et al. (2020)
Potato	Anthocyanin	Negligible	>0.60 ppm	Yadava et al. (2020)
Sweet Potato	PVA	2–3 mg/100 g	>13 mg/100 g	Yadava et al. (2020)
	Anthocyanin	Negligible	>80 mg/100 g	Yadava et al. (2020)

10.2.2 Genetic Engineering

Genetic engineering is a modern tool for generating transgenics and has also been deployed to transgenes directly into elite genotypes for increasing yield, tolerance to biotic and abiotic stresses, and effectively sustainably fighting against minerals, vitamins, and protein deficiency. It is the third and modest approach to biofortification for enhancing nutrient concentration in crops, where the success rate and acceptability of breeding is much higher (Garg et al. 2018, Table 10.3). This approach can serve as a fast and cost-effective strategy to alleviate different micronutrients deficiency. A superior genotype, once developed, can be used for many years without any additional recurring cost. However, it also has some limitations (Table 10.4).

The genetic engineering-based bio-fortification of crops emerges as a self-targeted and non-recurrent approach to address micronutrient malnutrition or hidden hunger, especially, where breeding is not possible due to lack of genetic

Table 10.3 Nutrition level improvement in different crops through genetic engineering system

Crops	Transformation systems	Targeted gene(s)	Targeted tissue	Total increase in nutrition levels	Author(s)
Iron					
Rice	*Agrobacterium*	Overexpression of soybean ferritin gene *Soyfer H-1*	Endosperm	38.1 µg/g DW	Goto et al. (1999)
Rice	*Bombardment*	Soybean *ferritin*	Leaves	99.00% ppm Dw	Drakakaki et al. (2000)
Rice	*Agrobacterium*	*Phaseolus ferritin*	Endosperm	22.07 µg/g/seed DW (2-fold higher than the control)	Lucca et al. (2001)
Rice	*Agrobacterium*	SoyferH2, soybean Ferritin gene	Endosperm	4.0 µg/g DW (4.4 times higher than the control)	Masuda et al. (2012)
Rice	*Agrobacterium*	Barley nicotianamine synthase gene *HvNAS1*	Endosperm	4.5-fold higher than the control	Masuda et al. (2009)
Rice	*Agrobacterium*	Soybean *ferritin*, *Aspergillus flavBous* phytase, *OsNAS1*	Endosperm	6-fold higher iron concentration-fold higher Fe than the control	Wirth et al. (2009)
Rice	*Agrobacterium*	*Overexpression of two OsNAS2*	Endosperm	19–81 µg/g DW (4-fold increased)	Johnson et al. (2011)
Wheat	*Bombardment*	Soybean *ferritin*	Leaves	47% ppm DW	Drakakaki et al. (2000)
Wheat	*Bombardment*	y1and *crtI*	Endosperm	4.96 µg/g DW (10.8-fold)	Cong et al. (2009)
Zinc					
Rice	*Agrobacterium*	Barley nicotianamine synthase gene *HvNAS1*	Endosperm	35 µg/g (>2.5 fold)	Masuda et al. (2009)
Rice	*Agrobacterium*	Overexpression of *two OsNAS2*	Endosperm	30–95 µg/g (2.5-fold increased	Johnson et al. (2005)
Vitamin A					
Rice	*Agrobacterium*	*Photoene synthase (psy)* from daffodil, *phytoene desaturase (CrtI)* gene from *Erwinia uredovora*	Endosperm	1.6 µg/g DW	Ye et al. (2000)
Rice	*Agrobacterium*	*Phytoene synthase (psy)* from maize, *Crtl* from the *Erwinia uredovora*	Endosperm	37 µg/g DW (23-fold than the original golden rice)	Paine et al. (2005)

(continued)

Table 10.3 (continued)

Crops	Transformation systems	Targeted gene(s)	Targeted tissue	Total increase in nutrition levels	Author(s)
Rice	*Agrobacterium*	*psy and lycopene β-cyclase (β-lcy)* both from daffodil (*Narcissus pseudonarcissus)*	Endosperm	1.6 μg/g DW	Beyer et al. (2002)
Rice	*Agrobacterium*	*crt1, psy1* and *pmi*	Endosperm	1.96–7.31 μg/g DW	GoC (2018)
Maize	*Bombardment*	Bacterial *crtB* and *crtI*	Endosperm	9.8 μg/g DW (>34 fold increased)	Aluru et al. (2008)
Maize	*Bombardment*	*Zmpsy1* and *PacrtI*	Endosperm	60 μg/g β-carotene (112-fold increased)	Naqvi et al. (2009)
Wheat	*Bombardment*	*psy* (maize) *and crtI (Erwinia uredovora)*	Endosperm	4.96 μg/g DW	Cong et al. (2009)
Ascorbate					
Maize	*Bombardment*	Dehydroascorbate reductase (*dhar*)	Endosperm	110 μg/g DW (6-fold Ascorbate)	Naqvi et al. (2009)
Folate					
Maize	*Bombardment*	*E. coli folE*	Endosperm	1.94 μg/g DW	Naqvi et al. (2009)
Vaccine					
Rice	*Agrobacterium*	*7Crp*	Endosperm	15% of total seed protein	Takaiwa (2007). Yang et al. (2007)

variability or when a particular micronutrient does not naturally exist in crops (Garg et al. 2018; Kumar et al. 2019). In this system of developing transgenic crops for micronutrients biofortification, two criteria are considered the most important such as (i) selection of widely adapted genotype of economically important crops, and (ii) accumulation of nutrients in the edible portion of the crop plant with diverse effect on plant physiology or development and economic yield, human health, ecology, and environment (Vanderschuren et al. 2013). This technique is a valid alternative where conventional plant breeding system fails to achieve significant genotypic improvement in nutritional levels in crops (e.g., provitamin A in rice), or when the conventional breeding cannot address the crop plants having propagated vegetatively (e.g., banana).

Development of transgenic biofortified crop initially involves substantial amount of time, efforts, and investment during new variety research and development stage, but in a long run it is a cost-effective and sustainable approach (Table 10.4). This system has no taxonomic barriers and even synthetic genes can be constructed and

Table 10.4 Biofortification strategies for enhancing micronutrients in food

SN	Biofortification strategies	Tools of biofortification	Pros	Cons
1	**Food fortification**	Wheat and rice with Fe, Vit.12 & Folic acid Milk & edible oil with Vit. A & D Double fortified salt with iodine & Fe Other details in Table 10.5	1. Cost-effective 2. Lower the risk of multiple deficiencies 3. Does not require any behavior change 4. An overdose of nutrients is unlikely 5. Not altered its intrinsic characteristics of food	1. A small amount of food intake is less likely to benefit 2. Same recurrent cost year after year, therefore, ordinary people cannot afford to buy the staples without funding support 3. Feasible for developed countries only and quite limited to small farmers and rural poor in developing countries 4. No long-term solution 5. Only complementary but not a replacement
2	**Biofortification**			
2.1	Agronomic	Mineral fertilization: foliar and soil mineral fertilizing Other details in Table 10.6	1. Simple, inexpensive, rapid enhancement 2. Does not require any food intake behavioral change 3. Overdose of nutrition is unlikely 4. Intrinsic characteristics of food are not altered	1. Only works with minerals; very dependent on crop and cultivar; not possible to target edible organs 2. The rural poor cannot afford and access micro-nutrient fertilizers 3. Application of imbalance dose may affect the health and yield of plants thereby affecting the grain micronutrients.
2.2	Conventional plant breeding	Using genetic variability for the development of micronutrient-enhanced crop varieties Other details in Table 10.2	1. Uses intrinsic properties of crop 2. New variety development with desired traits for micronutrients 3. A well-accepted and sustainable method 4. Varieties able to uptake higher levels of micronutrients from the soil	1. Depends on existing gene pool; takes a long time; traits might need to be introgressed from wild relatives; possible intellectual property rights or regulatory constraints 2. Limits the effective uptake of micronutrients from the micronutrient deficit soil 3. Limited due to the non-availability of enough genetic variability in the gene pool 4. Genetic exchange is possible between closely related species 5. Needs special requirement to produce grain and seed

(continued)

Table 10.4 (continued)

SN	Biofortification strategies	Tools of biofortification	Pros	Cons
2.3	Genetic engineering/ modification technology	Molecular breeding: Marker-assisted breeding, Genetic engineering (Transgenic/ cisgenic, ZFNs, TALENs, CRISPR/cas9) of direct genes introduction or manipulation into target crops Other details in Table 10.6	1. Rapid; unconstrained by gene pool; targeted expression in edible organs; applicable directly to elite cultivars 2. Modern tools for generating new crop varieties crossing between related or unrelated species 3. Superior variety can be used for many years 4. Useful for bio-vaccine also	1. Regulatory landscape; political and socio-economic issues relevant to transgenic plants; possible intellectual property constraints 2. Environmental impact assessment is time and cost consuming 3. Farmers and consumers may not accept it easily 4. Requires high-tech human resources and sophisticated laboratory

used with its construct (promoter-gene-terminator). Several crops have been genetically modified to enhance micronutrients (Garg et al. 2018, Table 10.3). Among micronutrients, minerals, vitamins, protein, fatty acids, bio-vaccines have been targeted by using various genes to improve nutrients in food crops (Garg et al. 2018, Table 10.3). In addition, with the advances of powerful new gene-editing tools like transcription activator-like effector nucleases (TALENs) and CRISPR/Cas9 and increased availability of fully sequenced genomes in staple crops have created new rooms for this biofortification (Nemudryi et al. 2014; Kumari et al. 2021).

In addition, transgenic technology is also used to develop biopharmaceutical plants for a natural plant vaccine. For example, the transgenic rice (*7Crp*)-based edible vaccine is effective for the treatment of Japanese cedar pollinosis when transgenic rice grain containing the structurally disrupted CryJ1 and CryJ2 antigens (universal antigen) is orally administered. The clinical symptoms of pollinosis, sneezing frequency and infiltration of inflammatory cells such as eosinophils and neutrophils were also significantly reduced in the nasal tissue (Takaiwa 2007; Yang et al. 2007). The consumption of approximately 12 g of 7Crp rice (at approximately 50 mg per 20 mg of grain) per day should be sufficient. Japanese citizens eat approximately 100 g of rice per day as a staple food, and therefore 7Crp seed can be used to supplement the daily diet by mixing with normal rice (Takaiwa 2007). Biopharmaceutical plants may need to be grown in a contained environment, with either physical or geographic isolation (Takaiwa 2007).

Currently, some organizations such as the World Health Organization (WHO), the Consultative Group on International Agricultural Research (CGIAR), Food Agricultural Organization, Global Harvest Initiative (GHI), HarvestPlus and Global Alliance for Improved Nutrition (GAIN) have been involved in developing biofortified high yielding crop varieties using biotechnological tools to address the deficiency of iron, zinc, protein and vitamins (A, B9 (folate), B12 and other B vitamins) to narrow down the gap of "hidden hunger" or nutrition security in the world in general and developing countries in particular. Breeding approaches have also greater role on improving human health through developing specific nutrient rich as well as specialty varieties.

10.2.3 Biofortification Strategy

Biofortification is a short- to a long-term strategy to increase the number of essential micro- and macronutrients in the major food sources that insure their bioavailability in the human body system. There are mainly two strategies for micronutrient fortification such as food fortification and biofortification of edible crops, which are common and effective in addressing malnutrition and micronutrient deficiencies (Kumar et al. 2019, Table 10.5).

Food fortification Food fortification is defined as the practice of **adding vitamins and minerals to commonly consumed foods during processing such as synthetic capsules or tablets, and** value-added cereals **to enhance the nutritional value for human health benefits with minimal risk to health** (Olson et al. 2021, Table 10.5). It is a proven, safe, and cost-effective strategy to improve micronutrients in foods (Table 10.4). In addition, existing systems of supplementations and food fortification of staple food with minerals and vitamins can address the issue of adequate nutrition security (Kumar et al. 2019). It is a strategy to fill the nutrient gap which has the advantage of being able to deliver nutrients to large segments of the population without requiring radical changes in their food consumption patterns (Kumar et al. 2019). Food fortification includes mass, target, market-driven (or commercial), household, (or community), and microbial fortifications. Food fortification has a decades-long global history that includes butter, margarine and sugar with vitamin

Table10.5 Food fortification

Food item	Fortifying nutrient or agent
Cereals	Vitamins, minerals
Beverages	Vitamins, minerals
Infant formulas, cookies	Iron
Milk, margarine	Vitamin A, D
Oil	Iron, vitamin A
Salt	Iodine, iron
Soy milk, orange juice	Calcium
Sugar, monosodium, glutamate, tea	Vitamin A
Vegetable mixtures amino acids, proteins	Vitamins, minerals
Wheat whole flour (Aata)	Vitamin D, synthetic vitamin A, iron
Wheat flour (Maida), bread, rice	Folic acid, vitamin B1, 2, 12; niacin, iron

Source: Modified from Sirohi et al. (2018)

A, salt with iodine, vitamin with milk, and vitamin B in cereals in many countries. However, there are still some drawbacks to current food fortification practices in the world (Table 10.4).

Bio-fortification Biofortification or biological fortification is an approach to enhance the micronutrient (minerals and vitamins) contents of agricultural produce with increased bioavailability to the human population that is developed and grown using modern agronomic practices, conventional plant breeding and biotechnology techniques (Garg et al. 2018). It also involves strategies that spin around targeting modulation of movement pathway (root uptake, transport, remobilization, storage, and enhanced bioavailability) of mineral nutrients, pulling nutrients from the soil, and pushing them to economic parts of plants in their bioavailable forms (Kumar et al. 2019). Garg et al. (2018), Hefferon (2019), Kumar et al. (2019) highlighted three systems of biofortification in plants, including agronomic, conventional plant breeding and genetic engineering (modern biotechnology). Biofortification of agricultural crop varieties offers a cost-effective, timely availability, sustainable and long-term solution approach to providing micronutrient-rich crop varieties to the needy and poor people, especially the people in developing countries (Garg et al. 2018). However, genetic engineering was found to be the most effective than agronomic and conventional breeding biofortification systems.

Agronomic biofortification The application of micronutrients or inorganic minerals such as iron (Fe), Selenium (Se) and zinc (Zn) fertilizers in the soil, foliar application, seed priming or coating of seed before planting, improves plant growth and development as well as biofortifying plants to improve nutrition for human consumption. High concentrations of zinc can be achieved in roots and left with soil fertilizer and even with foliar Zn-fertilizers (Wei et al. 2012). Although the use of the externally added micronutrients in the form of fertilizer can be effective, the relative efficiency of biofortification can vary from one plant to another and nutrients available in the soils. Sometimes, if the application of micronutrients is more than the recommended dose, it is deleterious to plants. However, agronomic inputs such as fertilizers may be harmful to the environment, and not be affordable or accessible to the rural poor, particularly in the developing world. Micronutrients such as Zn concentrations in fruits, seeds, and tubers are generally significantly lower.

Generally, plants have ability to absorb enough Fe and Zn from the soil to meet their physiological and metabolic requirements if the soil is rich in Fe and Zn. Nearly 50% of cereal growing areas in the developing world have been found deficient in Zn, which leads to the lower concentration of Zn in the grain of crops grown in such soils (Graham and Welch 1996; Cakmak, 2008). The application of Fe, Se and Zn fertilizers possess different positive responses to improve the availability of these minerals in plant growth and development and their accumulation in the grains to improve nutrition for human consumption (Table 10.3). The micronutrients such as Fe, Se and Zn availability to plant also depends on its rate and time of application; the genetic makeup of the crop; soil moisture; availability of other fertilizer concentrations in the soil, and the environment where the crop is grown.

Table 10.6 Agronomic biofortification system used for Iron (Fe), Selenium (Se) and Zinc (Zn) micronutrients food fortification

Crops	Micronutrients	Methods of application	Nutrient increment in grains/seeds over control (%)	References
Rice (*Oryza sativa* L.)	Fe, se and Zn	Foliar spray	Fe: 37.1 Se: 194.1 Zn: 36.7	Fang et al. (2008)
	Fe	Foliar spray	67.2	He et al. (2013)
	Zn	Foliar spray	22.47–24.04	Wei et al. (2012)
		Foliar spray	26.18	Ram et al. (2016)
		Seed priming	580.0	Johnson et al. (2005)
Maize (*Zea mays* L.)	Zn	Foliar	35.2–42.9	Wang et al. (2012)
		Soil	51	Zhang et al. (2013)
		Soil and foliar	Soil: 43.9 Foliar: 45.6	Rehman et al. (2018)
Wheat (*Triticum aestivum* L.)	Zn	Foliar	26.4–32.3	Wang et al. (2012)
		Foliar spray	47.14	Ram et al. (2016)
		Seed priming	900.0	Johnson et al. (2005)
Chickpea (*Cicer arietinum* L.)	Fe and Zn	Foliar spray	Fe: 34.54–35.28 Zn: 17.68–19.20	Pal et al. (2019)
	Zn	Seed priming	1067.0	Johnson et al. (2005)
Common beans (*Phaseolus vulgaris*)	Zn	Foliar spray	15.04	Ram et al. (2016)
Lentil (*Lens culinaris*)	Zn	Seed priming	1160.0	Johnson et al. (2005)

High concentrations of iron and zinc can be achieved in plant roots and leaves by application of Fe and Zn-fertilizers in soil and on foliar (Table 10.5). The seed priming was found to be more effective to increase the Zn content in rice, wheat, chickpea, and lentil (Johnson et al. 2005, Table 10.3). However, Harris et al. (2008) reported that seed priming of chickpea and wheat with Zn significantly increased grain Zn concentration by 29% and 12% respectively, which is far lower than report made by Johnson et al. (2005) (Table 10.6). Hence, the foliar application of Zn alone was also found to be effective to increase the grain Zn concentration in wheat by 84%, while soil Zn application showed an average increase of 12% over control (Zou et al. 2012). The response of these fertilizers is crop as well as the method of application-specific. For example, among rice, wheat, chickpea, and lentil the response of chickpea to seed priming with Zn was found to be the highest grain zinc content followed by lentil, wheat, and rice (Johnson et al. 2005), whereas, among rice, wheat, and maize, the response of wheat to foliar Zn application was the highest, followed by rice and maize (Table 10.6). Generally, Zn concentrations in fruits, seeds, and tubers are significantly lower using agronomic biofortification. Hence, micronutrient fertilizers may not be affordable or accessible to the rural poor in developing countries.

10.2.4 Other Nutritional and Human Health Issues

In addition to manipulation of major nutrients, there are many other potential of using crop breeding for better providing nutrition and health to human. Though very few studies have been observed, followings are potential areas of crop breeding to improve the nutrition security and human health.

- Plant based vaccine could be produced by developing varieties using biotechnological tools.
- Nutrient contents of any economical yield of any variety are major important for nutrition security and human health. Crop breeding can breed genotypes with higher protein content as well as very specific nutrient-dense varieties.
- Consumers prefer to have food with high energy provider, rather than amount. There is a need to considering research on developing varieties that produce grains and economical parts with high energy.
- There are many success cases of treatment of human diseases by eating very specific foods and herbs. Breeding on herbal plants are very limited. To improve the health of human, chemists and plant breeders need to work together so that specific human disease suppressor can be identified and incorporated in the varieties as well content plant development. In many areas, there are plant species which generate higher amount of oxygen. Varieties with such traits if developed, could be very important to human health.
- The requirement of types of food and their nutrient composition differs from children to adult to aged people. Varieties suitable to different age-people could be bred, so that people can easily get balance nutritional and easily digestible foods.
- To be healthy, consumers prefer food with low glycemic index and high rutine content food. Many people aware now a days to have lectin and gluten free food. Crop breeding has greatly contributed to develop varieties with these properties.

10.3 Breeding for Environmental Security

The production of food has soared in recent decades as populations have boomed and global economies have improved. As a result of this growing demand, the food industry is now negatively impacting the planet like never before. Massive amounts of planet-warming greenhouse gas emissions are released every year from the production of food, water resources are being depleted and contaminated, and important ecosystems are being destroyed by deforestation for pastures and crops (Statistica 2021). Environmental biotechnology (EB) is one field of biotechnology that can play a positive and important role in detoxifying and eliminating pollutants and cleaning up the contaminated sites of ecosystems (Gu 2021). Environmental biotechnology involves the utilization of biotechnological processes that have applications in waste and wastewater treatment, bioremediation, bioleaching, biofuels, and biopolymers which contribute to controlling environmental pollution. It is also integrated with agricultural biotechnology for those applications and focuses on modifying microorganisms and other living organisms including plants for such purposes. Identification of useful microorganisms and their candidate genes can be utilized in agricultural biotechnology for developing improved biotech crops. Biotech crop farming has a lot of controversies and has faced resistance in the past. Some of governments have banned all GMO crops in their countries. The controversies mainly involve government regulations, biotechnology companies, and scientists. Some of the areas of concern include the health of the consumer, impact on the environment, impact on farmers, and government regulations. Some of the advocacy groups like the Center for Food Safety have called for a thorough examination of the risks associated with GM food before it is allowed for consumption even though scientists have persisted that GMO food poses no threat to life (WorldAtlas 2017). The benefits and challenges of genetically modified crops have attracted enormous public attention, primarily around four issues: food safety, toxicity and pest resistance, crop yield effects, and shifts in profits and control to major corporations. Although the merits of existing GM crops can be debated, GM technology may offer other useful potential benefits, particularly traits that help crops resist diseases that cannot be addressed by any other means (World Resources Institute 2014).

The world needs to close a 69% gap between the crops produced in 2006 and the crops that the world needs by 2050. Assuming the present course of diets, population growth, and rates of food loss and waste, crop yields will need to grow one-third more in the coming 44 years than they did in the last 44 years to avoid net expansion of harvested cropland (World Resources Institute 2014). Genetically modified (GM) crop technology has been used by many farmers around the world for more than 20 years and currently nearly 17 million farmers a year plant seeds containing this technology (Brookes and Barfoot 2020). The technology is also changing agriculture's carbon footprint, helping farmers adopt more sustainable practices such as reduced tillage, which has decreased the burning of fossil fuels and allowed more carbon to be retained in the soil (Qaim and Traxler 2005; Brookes and

Barfoot 2020). Plant breeding contributes to reducing greenhouse gas emissions: about 3.4 billion tons of direct CO_2 emissions were avoided in Europe because of plant breeding innovation over the last 15 years (Europeanseed 2016). GM crop technology has been widely used for more than 20 years in many countries and is mainly found in the four crops canola, maize, cotton and soybean. While increasing global yield by 22%, GM crops reduced pesticide (active ingredient) usage by 37% and environmental impact (insecticide and herbicide use) by 18% (Klümper and Qaim 2014). Recently, the adoption of GM crops technology for insect-resistant maize, cotton and soybean, and herbicide-tolerant soybean, maize and canola has reduced the use of pesticides by 775.4 million kg (8.3%) and also decreased the environmental impact associated with it by 18.5% (Brookes and Barfoot 2020). Therefore, the genetic engineering technique aims at developing crops that are resistant to diseases, pests, and extreme environmental conditions while reducing spoilage and improving the nutrients of the produce. The crops are sometimes referred to as Genetically Modified Crops or simply as GMCs or biotech crops. High yield and low cost of pesticides have increased farm profitability. Because of improved profit margins, farmers in most countries have adopted biotech crop farming (WorldAtlas 2017). In 2018, crops containing this type of technology accounted for 48% of the global plantings of these four crops. In 2019, the total acreage of genetically modified crops worldwide came to some 190.4 million hectares. Genetic modifications of crops are done for many reasons, for example, to attain desirable traits or to make crops resistant to pests or herbicides. Since 2003, the acreage of genetically modified crops has generally been increasing, and globally, soybeans and corn are the most commonly adopted biotech products (Statistica 2022).

Concerning the environment, cultivars can be developed that require less tilling, thereby bringing down soil erosion and nitrogen leakage. More drought-tolerant cultivars will decrease the need for irrigation which is a major cause of environmental problems. Plants with improved nitrogen efficiency will diminish the use of fertilizers, and pesticide-resistant crops the use of pesticides (Houehanou et al. 2014). It is widely accepted that increases in atmospheric levels of greenhouse gases such as carbon dioxide, methane and nitrous oxide are detrimental to the global environment. Therefore, if the adoption of crop biotechnology contributes to a reduction in the level of greenhouse gas emissions from agriculture, this represents a positive development for the world (Intergovernmental Panel on Climate 2006).

Currently, commercialized genetically modified (GM) crops have reduced the impacts of agriculture on biodiversity through enhanced adoption of conservation tillage practices, reduction of insecticide use and use of more environmentally benign herbicides and increasing yields to alleviate pressure to convert additional land into agricultural use (Carpenter 2011). Most of the genetically modified (GM) plants currently commercialized encompass a handful of crop species (soybean, corn, cotton and canola) with agronomic characteristics (traits) directed against some biotic stresses (pest resistance, herbicide tolerance, or both) and are created by multinational companies (Ricroch and Hénard-Damave 2016) for enhanced productivity, socio-economic benefit and environmental security. Some of the biotech crops developed through advanced breeding technologies for reducing the impact of agrochemical use and environmental pollution are discussed below.

10.3.1 Breeding Crops for Reduced Herbicide and Pesticide Use

The release of herbicide-tolerant glyphosate-tolerant Roundup Ready® from Monsanto and glufosinate-tolerant Liberty Link® from Bayer is known as the first commercialized transgenic crop in the USA in the 1990s (Heap 2014). Even though the adoption of glyphosate-tolerant crops has resulted in weed species developing resistance to the herbicide (ISAAA 2017), transgenic crops are accepted and cultivated in several areas in the world and contributed much more in terms of reducing chemical herbicide use and reducing the environmental pollution. Even though efforts are there in creating transgenic crops, only a few are being commercialized. Mostly commercial crops such as maize (*Zea mays*), soybean (*Glycine max*), and cotton (*Gossypium* sp.) are used in research due to the high cost of research work. In terms of wheat and rice, even though several transgenic traits are produced such as glyphosate-tolerant wheat (Hu et al. 2003) and Golden Rice (Ye et al. 2000), they seem to be absent from the commercial scale.

Tolerance to specific herbicides (notably glyphosate and glufosinate and tolerance to additional active ingredients like 2 4 D and dicamba) in maize, cotton, canola (spring oilseed rape), soybean, sugar beet and alfalfa has been achieved in the last decade (Brookes and Barfoot 2020). This GM Herbicide Tolerant (GM HT) technology allows for the 'over the top' spraying of GM HT crops with these specific broad-spectrum herbicides, that target both grass and broad-leaved weeds but does not harm the crop itself. Resistance to specific insect pests of maize, cotton, soybeans and brinjal using GM insect resistance (GM IR), or 'Bt' technology offers farmers resistance in the plants to major pests such as stem and stalk borers, earworms, cutworms and rootworm in maize, bollworm/budworm in cotton, caterpillars in soybeans and the fruit and shoot borer in brinjal. Instead of applying insecticide for pest control, a very specific and safe insecticide is delivered via the plant itself through the 'Bt' gene expression. In addition, the GM papaya and squash referred to above are resistant to important viruses (e.g., ringspot in papaya), the GM apples are non-browning and the GM potatoes have low asparagine (low acrylamide which is a potential carcinogen) and reduced bruising (Brookes and Barfoot 2020). Development of those genetically modified crops has significantly reduced the use of agrochemicals reducing environmental pollution as well as conserving biodiversity.

Important environmental benefits have also occurred in China and India from the adoption of genetically modified insect resistant (GM IR) cotton, with a reduction in insecticide active ingredient use of over 276 million kg (1996–2018). The adoption of GM insect resistant and herbicide tolerant technology has reduced pesticide spraying by 775.4 million kg (8.3%) and, as a result, decreased the environmental impact by 18.5% associated with herbicide and insecticide use on maize, soybean, canola and/or cotton crops (as measured by the indicator, the Environmental Impact Quotient (EIQ)). The technology has also facilitated important cuts in fuel use and tillage changes, resulting in a significant reduction in the release of greenhouse gas emissions from the GM cropping area. In 2018, this was equivalent to removing 15.27 million cars from the roads (Brookes and Barfoot 2020).

Biotech herbicide tolerance (HT) technology has facilitated changes in farming systems. Thus, biotech HT technology (especially in soybeans) has played an important role in enabling farmers to capitalise on the availability of a low-cost, broad-spectrum herbicide (glyphosate) and in turn, facilitated the move away from conventional to low/no-tillage production systems in both North and South America. This change in the production system has delivered important environmental benefits, notably reduced levels of GHG emissions (from reduced tractor fuel use and additional soil carbon sequestration). Concerning biotech HT crops, however, over-reliance on the use of glyphosate by some farmers, in some regions, has contributed to the development of weed resistance. As a result, farmers are increasingly adopting a mix of reactive and proactive weed management strategies incorporating a mix of herbicides. Despite this, the overall environmental gains arising from the use of biotech crops have been, and continue to be, substantial (Brookes and Barfoot 2012).

Transgenic *Arabidopsis* and tobacco plants that express EbF synthase genes from peppermint and sweet wormwood have been demonstrated to repel aphids and attract their natural enemies, including ladybugs and parasitoid wasps. This technology would remove the practice of applying insecticides, which are undesirable both for causing environmental harm as well as inviting the possibility of insecticide resistance (Hefferon 2016). Recently, several commercial products have been available with multiple herbicide-tolerant traits. The use of single lepidopteran insect resistance genes derived from *Bacillus thuringiensis* in Bt cotton, Bt maize, Bt potato, etc. is the best examples known to save the agricultural industry from great losses. The combination of insect resistance and herbicide-resistant traits is considered a turning point in transgenic crops. The percentage of the planted area has been found to grow with this especially in USA and Brazil (Ma et al. 2017) contributing to decreased use of chemical herbicides and pesticides thus promoting organic agriculture.

Introduction of g-glutathione synthetase, a GST gene, into poplar plants leads to higher concentrations of glutathione, and the plants show tolerance toward two chloroacetanilide herbicides, acetochlor, and metolachlor (Gullner et al. 2001). Indian mustard (*Brassica juncea*) expressing this gene shows increased tolerance to atrazine, 1-chloro-2,4-dinitrobenzene (CDNB), metolachlor, and phenanthrene (Flocco et al. 2004). Maize GSTs are known to detoxify triazine and chloroacetanilide herbicides, and transgenic tobacco plants expressing maize GST I have been shown to remediate alachlor (Karavangeli et al. 2005). In rice, GSTs conjugate the herbicide prechirachlor with glutathione, a reaction induced by the safener fenclorim (Scarponi et al. 2003). Using RNAi, GST activity toward cinnamic acid, CDNB, and prechirachlor can be reduced by as much as 77% in transgenic calli (Deng et al.

2003). These studies demonstrate the important role of GSTs in protecting plants against general herbicide stress contributing for reducing the negative impact of herbicides on the environment.

In addition to the approaches involving P450 and GST genes, various transgenic plants that exhibit herbicide tolerance can be used for phytoremediation. Transgenic alfalfa, tobacco, and *Arabidopsis* plants expressing a bacterial atrazine chlorohydrolase (atzA) gene show enhanced metabolic activity against atrazine (Wang et al. 2005). These innovations in plant biotechnology have a great advantage in the elimination and detoxification of agrochemicals used in agriculture thus controlling environmental pollution.

10.3.2 Breeding Crops for Reduced Fuel Use and GHG Emission

The fuel savings associated with making fewer spray runs in GM IR crops of maize and cotton (relative to conventional crops) and the switch from Conventional Tillage (CT) to Reduced Tillage or No Tillage (RT/NT) farming systems facilitated by GM HT crops have resulted in permanent savings in carbon dioxide emissions. The widespread adoption and maintenance of RT/NT production systems in North and South America, facilitated by GM HT crops (especially in soybeans), has improved growers' ability to control competing weeds, reducing the need to rely on soil cultivation and seed-bed preparation as means to getting good levels of weed control. As a result, as well as tractor fuel use for tillage being reduced, soil quality has been enhanced and levels of soil erosion cut. In turn, more carbon remains in the soil and this leads to lower GHG emissions. In 2018, this amounted to a saving of 2456 million kg of carbon dioxide, arising from reduced fuel use of 920 million liters. The largest fuel use-related reductions in carbon dioxide emissions have come from the adoption of genetically modified herbicide technology (GM HT) technology in soybeans. These savings have been the greatest in South America. Over the period 1996–2018, the cumulative permanent reduction in fuel use has been about 34,172 million kg of carbon dioxide, arising from reduced fuel use of 12,799 million liters. In terms of car equivalents, this is equal to taking 22.65 million cars off the road for a year (Brookes and Barfoot 2020).

10.3.3 Breeding Crops for Reclamation of Soil and Water

Phytoremediation of herbicides has been well studied using conventional plants. Transgenic plants produced for metabolizing herbicides and long-persisting pollutants can be used for the phytoremediation of foreign chemicals in contaminated soil and water. The genes involved in the metabolism of chemical compounds can be isolated from various organisms, including bacteria, fungi, plants, and animals, and these genes are then introduced into candidate plants. Transgenic plants expressing mammalian P450s and the other enzymes showed tolerance and phytoremediation activity toward target herbicides. Transgenic plants can also enhance the absorption and detoxification of pollutants, thereby aiding the phytoremediation of contaminated environments (Kawahigashi 2009). As with P450s, several GSTs seem to be involved in herbicide metabolism in plants. The genetic engineering of plants to facilitate the reclamation of soils and waters contaminated with inorganic pollutants is a relatively new and evolving field, benefiting from the heterologous expression of genes that increase the capacity of plants to mobilize, stabilize and/or accumulate metals. The efficiency of phytoremediation relies on the mechanisms underlying metal accumulation and tolerance, such as metal uptake, translocation and detoxification. The transfer of genes involved in any of these processes into fast-growing, high biomass crops may improve their reclamation potential (Fasani et al. 2018). So far, positive results for either phytostabilization of heavy metals in soils, or their removal, were achieved with the yeast vacuolar transporter YCF1 gene (Shim et al. 2013), and metal ligands (Martínez et al. 2006) that are efficient in inducing both tolerance and accumulation by allowing metal chelation and compartmentalization. Regarding the specific instance of Hg decontamination, the combination of bacterial merA and merB genes has proved promising in a wide variety of species tested, including fast-growing trees such as poplar (Dai et al. 2009).

Similarly, the phosphorus absorbance of plants has been enhanced using genetic transformation (Hirsch and Sussman 1999). Engineering plants to enhance their ability to efficiently absorb soil nutrients can reduce the use of harmful agrochemicals, in turn reducing environmental pollution. Also increasing the tolerance of the crops to withstand high metal levels in the soil is also practiced in tobacco (*Nicotiana tabacum*) and papaya (*Carica papaya*) plants in making them tolerant to aluminum (De la Fuente-Martínez and Herrera-Estrella 1999).

Similarly, tobacco plants transformed with an extracellular fungal laccase from *Coriolus versicolar* (Sonoki et al. 2005) secrete laccase into the rhizosphere and remove the pollutants bisphenol A and PCP with high efficiency (20 mg per gram dry weight). For TNT, tobacco plants have been genetically engineered to express a bacterial (*Enterobacter cloacae*) NADPH-dependent nitroreductase, which enhances conversion to aminodinitrotoluene within the roots of the engineered plants. Plants expressing the bacterial gene tolerate and degrade TNT, at levels lethal to wild-type plants. Interestingly, the plants also naturally contained an enzyme that could remove the toxic aminodinitrotoluene. Similarly, a gene *XplA* has been transferred from *Rhodococcus rhodochrous* into the plant *Arabidopsis thaliana* with subsequent decontamination of RDX (Vaishnav and Demain 2009).

10.3.4 Breeding Crops for Oil Spills and Explosives Pollution Control

The use of inherent aquatic plants along with recent omics tools have been used to improve the aquatic plant's phytoremediation ability to a great extent for controlling aquatic pollution (Agarwal and Rani 2022). These plants have an extensive root system that can filter and immobilize sediments, contaminants, fertilizer and pesticide run-off thereby reducing water pollution. Free-floating aquatic plants of the Lemnaceae family, mostly *L. minor*, can transform and eliminate azo-dyes like Acid blue dye (AB92) and other textile dyes by converting them into their by-products(Ansari et al. 2020; Khataee et al. 2012). American waterweed (*Elodea sp.*) is also known to bioaccumulate and phyto transform the DDT (dichlorodiphenyltrichloroethane) into DDD (Ekperusi et al. 2020). A study in duckweed indicated that *L. paucicostata* bioaccumulated less than 1% and significantly biodegraded 97.74% of hydrocarbons in wetlands and it is reasonable to infer that *L. paucicostata* is an effective aquatic macrophyte for the removal of petroleum hydrocarbons in moderately polluted waters (Ekperusi et al. 2020). Azolla and *H. verticillata* are reported to have the ability to remediate the toxic fly ash from the water body (Pandey 2012; Srivastava et al. 2010). Duckweed is popularly known for transforming the higher carbon chain hydrocarbons into lower carbon chain hydrocarbons (C30–C40), which are eventually conjugated and sequestered by the plants (Ekperusi et al. 2020; Agarwal and Rani 2022). Studies found that *E. crassipes* (water hyacinth) can be an effective aquatic plant for phytodegradation of bisphenol A (2,2-bis (4-hydroxyphenyl) propane) and ethion from pesticide-contaminated water (De Laet et al. 2019; Dhir 2013). Aquatic macrophytes that can survive in contaminated environments and can detoxify the water bodies include species of *Lemna, Eichornnia, Pteris, Wolfia, Spirodela, Hydrilla, Pistia, Typha* and *Crysopogon,* etc. (Agarwal and Rani 2022). Genomic approaches have identified genes that play an important role in the tolerance mechanisms and phytoremediation ability of the plant toward various contaminants (Agarwal and Rani 2022).

Studies of proteomic changes in the hyperaccumulator plant *Phytolacca americana* upon exposure to Cd stress revealed that 11 genes that were found responsible for photosynthesis and glutathione metabolism pathway were downregulated. Similarly, a proteomic study in Al stressed *Glycine max* revealed 21 proteins were attributable to the antioxidant defense system and were upregulated while 14 newly stored and 5 other proteins were downregulated (Agarwal and Rani 2022). These newly formed proteins were found to be concomitant with signal transduction, biosynthesis of cysteine synthase enzyme and sulfur metabolism in plant cells, which was confirmed with western blot. A somatic hybrid developed using *T. caerulescens* and *B. napus* and *T. caerulescens* and *B. juncea* showed enhanced biomass production and more Zn accumulation and Pb phytoextraction respectively (Rascio and Navari-Izzo 2011). A transgenic *Petunia* hybrid plant with the *CAXcd* (an Arabidopsis CAX1 mutant) gene for enhanced Cd tolerance and accumulation was also reported (Wu et al. 2011). The transgenic plants were able to accumulate up to 2.5 times more Cd than the controls. Similarly, transgenic *B. juncea* can better remediate selenium from contaminated soil as well as hydroponically, by the expression of *APS* (ATP sulfurylase) and *SMT* genes. Moreover, it is critically important to understand the functions and regulations of genes involved in metal uptake, hyperaccumulation, translocation via the xylem, detoxification and sequestration mechanisms to strategically manage the contaminated water systems without harming the wild species of the plants (Agarwal and Rani 2022). For the enhanced phytoremediation of organic or refractory pollutants, transgenic tobacco was used to express several genes comprising Nfs1 (encodes for nitroreductase), onr gene (organic nitrate reductase) that encodes for pentaerythritol tetranitrate reductase enzyme, (PETN) for the enhanced removal of GNT and TNT (Abhilash et al. 2009). It was also reported that the use of CYP450 2E1 (Cytochrome P450 Monooxygenase enzyme) gene in *N. tobaccum* can be used for the enhanced degradation of TCE, ethylene dibromide, anthracene and chlorpyriphos (Dixit et al. 2008). Up-regulation of ECS and GS in transgenic *B. juncea* can be used to amplify tolerance of plants towards atrazine, 1-chloro-2, 4-dinitrobenzene, phenanthrene, metolachlor (Flocco et al. 2004). XplA and XplB genes isolated from a soil bacterium, *Rhodococcus rhodochorus* (genus Nocardiaceae) were used to increase detoxification of RDX in *A. thaliana* plants as reported by Jackson et al. (2007). *Solanum tuberosum* was modified using CYP1A1, CYP2B6 and CYP2C19 to improve the resistance of transgenic plants toward sulfonylurea and other herbicides (Inui and Ohkawa 2005).

CRISPR-mediated strategy for enhanced phytoremediation focuses on scrutinizing and expressing the target genes to upsurge the synthesis of metal ligands, metal transporters, increased phytohormones and root exudates (Rai et al. 2021; Basharat et al. 2018). A plasma membrane protein (NtCBP4) was introduced in *N. tobaccum* plants for enhanced accumulation of lead in the plant, but simultaneously it caused sensitivity towards Pb in the plant system. Similar results were found when the MerC gene was transferred and expressed in two model plants, *Arabidopsis* and tobacco plants, causing sensitivity in these plants to mercury (Hg). Additionally, similar reports against the organic pollutants are also reported that such sensitivity against RDX and TNT was observed in the transgenic plants being developed for enhanced phytoremediation of these organic contaminants (Jaiswal et al. 2019). Yang et al. (2019) have reported the use of the CRISPR/ Cas9 system to produce the OsNRAMP5 knockout plants for meliorating the tolerance of *O. sativa* exposed to Cd stress.

Evaluation of the biodiversity and life forms of plant species in the impacted sites showed that phytoremediation with *C. esculentus*, alone or in a mix-culture with *C. laxus* and *L. peploides*, reduces the TPH (total petroleum hydrocarbons) to such an extent that the native plant community was progressively reestablished by replacing the cultivated species resulting in the ecological recovery of the affected soil. From the phytoremediation treatments, a mix-culture of *C. laxus*, *C. esculentus*, and *L. peploides* in soil removed 20.3% were polyaromatic hydrocarbons (PAH) and 34.2% were asphaltenes (ASF) and was able to remove up 93% of the TPH, while in unvegetated soil, the TPH removal was 12.6%. These results demonstrate that native Cyperus species from weathered oil spill-affected sites, specifically *C. esculentus* and *C. laxus*, alone or in a mix-culture, have potential for phytoremediation of soils from tropical wetlands contaminated with weathered oil hydrocarbons (Palma-Cruz et al. 2016). A study revealed that arsenic could be removed through volatilization from the contaminated soil by bacteria that have the *arsM* gene expressed ad it is possible to use microorganisms expressing *arsM* as an inexpensive, efficient strategy for arsenic bioremediation from contaminated water and soil (Liu et al. 2011). In addition, rice plant is efficient in arsenic (As) accumulation due to enhanced soil As release under flooded condition and its effective As uptake. Therefore, rice plant can be used to remove bioavailable As from paddy soil. The removal of rice roots resulted in ~19% lower the diffusive gradients in thin films (DGT)-As in post-harvest soil compared to without removing the roots (He et al. 2020). Therefore, the use of such information in plant breeding with the aid of genetic engineering and omics technology can be used as a successful tool for developing commercial crops with pollution-controlling properties considering the health and environmental benefit.

10.3.5 Breeding Plants for Other Environmental Issues

Agricultural research and production systems are not nature +ve in many areas. Due to which (in addition to other factors), environmental condition is deteriorating day by day. In breeding program, breeders paly more roles on determining the genotypes for next generation but in nature, environmental factors play crucial role to select the genotypes that suit best in next generation. Evolutionary population of any varieties are those populations, where environmental factors decide on advancing the progenies in next generation. Such population could be of greater role on tackling the different negative aspects of environment. Plant breeding has a very wide scope on dealing many following environmental conditions.

- Virus free plant from meristem tissue culture is an effective method for virus treatment, i.e. without using any chemicals and others compounds.
- Tissue culture can help to rescue the germplasm, which are at risk and not able to produce progeny. Even the number of plants within a short period can be made ready to transplant in environmentally degraded areas. This helps to restore the conditions in a faster way.
- Climate changes are the top most concern across the world and crop breeding is an option to develop the climate resilient crop populations. Faster growing varieties can be developed so that many drought areas can be made greenery.
- To speed up the restoration of degraded habitat, plant breeders can develop suitable broad genetic base varieties that suit to such areas.
- Production systems along with road side and city areas are affected by dust and other air and water pollutant. For such areas, dust and pollutant tolerant plant could be developed.
- The amount and types of waste are also increasing and they are damaging the production areas as well. Depending on the types of waste in the soil, adjustable varieties can be developed.
- With the advances on manipulating genetic makeup, nitrogen fixation plant varieties could be very effective means to increase the soil fertility. This helps to minimize the fertilizers required per unit area. Such nitrogen fixing system will also be useful to keep the air with balanced components.

- Ecological services are now decreasing in many areas. This is root cause of bad environments and for which suitable varieties which enhance the ecological services can be bred and grown in needy areas.
- To help purify the water and air purification, suitable varieties of different plant species can be developed as per the necessity of particular site.
- Soil erosion is another major problem on damaging the environment. Plant varieties with strong root system could be developed that helps to control soil erosion.
- Organic matter in the soil is very low in many production systems. To speed up the organic matter in the soil, high biomass producing plant varieties could be developed.

10.4 Breeding Constraints and Limitations

Along the technological advances, the nutritional aspects are being considered only on few crops e.g. rice, wheat, maize, lentil, etc. Under the environmental aspect, focus is only on drought, and insect pests. Health related crop breeding is almost none and there should be some initiation for breeding crops suitable for agro-hospital and agro-medical college. Static populations in the field along the rapid genetic erosion are creating havoc to getting the suitable genetic materials for better designing the genotypes for diverse human population and consumer demands. The advanced technologies, infrastructures and experts are not available in all countries for many different crop species especially on breeding for nutrition and environmental security. Conserving genetic diversity statically in Genebank and marketing single genotypes worldwide cannot favor evolution which is a must in the context of climate change, nutritional demand and health issues. Different varieties may be required to breed nutritionally suitable for different age people and can be produced at different seasons across the diversity agro-eco zones. This means large number of varieties of many different crops should be developed. Breeding strategies should also focus on improving underutilized crop species including local landraces in addition to major staple food crops for ensuring nutrition, health and environmental security. However, genetics of many underutilized crop species and landraces are not known.

The development of different nutrient-rich varieties is very costly and time-consuming. Nutrition profiling and metabolic assisted breeding demands both high skill and advance equipment. Crop breeding is far behind to support the new subject i.e. Medical Agriculture by developing varieties of agricultural medicine which are needed to run the agricultural hospital. The big challenge is breeding works with the concept of treatment and prevention of human diseases through healthy food, medicinal herb, agricultural exercise, balanced agroecosystem, waste management, nutrient-rich genotypes, and plant-based vaccines, etc.

Some of the areas of concern regarding the development and use of GM crops include the health of the consumer, impact on the environment, impact on farmers, and government regulations. However, a thorough examination of the risks associated with GM crops and their products before it is allowed for cultivation and consumption, is necessary. To get more environmentally friendly genetically modified crops for environmental security, it is important to use novel breeding approaches like omics technologies and genome editing tools to minimize the risk of transgenes being incorporated into new plants and for this, manpower is very limited across the world. All breeding researches are mostly carried out on chemical production system but for health and environment, varieties suitable for nature +ve production system have not been considered. To increase the soil organic matter, high biomass producing varieties are also very important and this aspect was given due attention in the past. To minimize the environmental shock to newly developed varieties, seed production and maintenance system of such varieties should be developed in such a way that, farmers can maintain seeds themselves without deteriorating genetic performance.

10.5 Conclusions

The major problems worldwide are food and nutrition insecurity, and environmental hazards including climate changes, pesticides, waste, etc. Worldwide, over 98% population is malnourished, mostly from developing countries such as South Asian and African continents. The environment is deteriorating day by day and human health is becoming challenging. Plant breeding plays a significant role for nutrition, human health and environmental security. Food fortification and biofortification (agronomic, conventional breeding and genetic engineering) approaches of edible crops are considered effective and have outstanding potential for ameliorating the problem of micronutrient malnutrition. Although food fortification is cost-effective and does not require any behavioral change, minimum risk, and no alteration of intrinsic characteristics of food; ordinary people cannot afford it without any financial support and not feasible for small farmers and rural poor in developing countries. Similarly, agronomic biofortification improves the grain nutrients such as iron, selenium, and zinc concentration for improving human health benefits. However, it is very crop and cultivar dependent, not possible to target edible organs, rural people cannot afford and access micro-nutrients and if its application dose is imbalanced, it may affect negatively to plant health and yield. With the advancement of conventional plant breeding systems, new crop varieties can be developed with desired micronutrient traits without disturbing their intrinsic properties, however, it takes a long time and depends on the existing gene pool. Therefore, advanced genetic engineering and molecular technologies such as transgenic/cis-genic, and genome editing are superior promising and sustainable tools for direct introducing or manipulating desired target genes to develop biofortified crop varieties. It is rapid, unconstrained by gene pool, targeted expression in edible organs, and apply directly to elite cultivars. The benefits and challenges of genetically modified crops have attracted enormous public concerns i.e., food safety, toxicity, pest resistance, crop yield effects and biosafety. Therefore, some regulatory, socio-economic, intellectual property rights, environmental and human health issues should be addressed properly which requires policy initiatives and government support for further research and development, and dissemination of biofortification technologies and practices globally.

Although GM technology is debated, it may offer other useful potential benefits by developing biotic and abiotic stress-resistant crops which ultimately reduce environmental pollution through reduced use of herbicides, pesticides, reduced greenhouse gas emissions, and other toxic pollutants of soil and water. Several novel biotechnological approaches have been developed to improve crops for enhanced yield, and biotic and abiotic stress resistance, however, the biosafety of those newly developed crops and their role in biodiversity conservation and environmental safety should be confirmed before cultivation, consumption and marketing globally. Crop breeding can also play an important role to improve the urban environment by developing suitable varieties for urban agriculture and dust-absorbing varieties to plant along the side of the road. Therefore, the adoption of new tools, technologies and approaches can help crop breeders to achieve a greener world, not only for increasing yield of any crops for farmers, but also for local communities who need nutritious crops/foods, healthy diet and a healthy environment. As there is necessity of consideration of nutrition, human health and environment aspects in plant breeding across the world, the number of breeders with the capacity of using different advanced tools, e.g. biotechnological, nutrient profiling, etc. should be increased in each country so that diverse types of varieties of many different plant/ crop species could be developed.

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Part IV
Micronutrient Concern

Chapter 11
The Micronutrient Zinc in Human Health and Disease

Young-Eun Cho, Sang-Hun Choi, and In-Sook Kwun

Abbreviations

Alb	Albumin
MT	Metallothionein
MTF-1	Metal regulatory transcription factor 1
TGC	Trans-Golgi cisternae
ZIP	Zrt-/Irt-like protein
Zn	Zinc
ZnT	Zn transporter

11.1 Introduction

Zinc is an essential metal for life. It is the major trace metal (element, mineral) in the human body, and is essential for many biological processes and is present in foods, soil and in living organisms such as plants and animals. It was about 1960s that zinc was recognized as an essential nutrient in humans for normal growth and development from the studies in the Middle East where zinc deficiency was prevalent in peoples (Cousins 1996). Since that time, zinc has been recognized that it is present in almost all the cells of the body and its function is essential for the cells.

The trace metal zinc is an essential cofactor for more than 300 enzymes physiological reactions and more than numerous transcription factors for gene expression for our body (Maret 2013a, b). In the central nervous system, zinc is the major trace metal and is involved in many neural processes and modulate neuronal activity. In addition to its role in enzymatic activity, zinc also plays a major role in cell signaling too.

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From the global view, zinc deficiency is particularly prevalent in underdeveloped and developing country due to the limits for zinc food sources and dietary pattern to prevent zinc bioavailability, where zinc deficiency is a challenges for optimal zinc nutriture. Zinc dysregulation of homeostasis is the causes of many chronic diseases in the another type of challenge for optimal human health.

In this chapter, we reviewed the function, absorption and metabolic regulation, cellular homeostasis mechanism, and symptoms under zinc deficiency and zinc-related diseases. We also emphasized the zinc role in human health and disease particularly reviewed the disease and symptoms under zinc deficiency in human. The contents of this review would provide to understand the possibility for sustaining optimal zinc nutriture and preventing the diseases by zinc deficiency.

11.2 Zinc Characteristics

Human intakes zinc as micronutrient from animal and plant food sources and zinc is only present in our body in trace amount, therefore daily intake of zinc is needed only in trace amount. Zinc is the first element in group 12 of the periodic table and exhibits only one oxidation state (+2) as Zn^{2+} in silver gray colored mineral (Table 11.1).

Zinc is an essential trace element for human (Prakash et al. 2015; Cherasse and Urade 2017) and other animals (Prasad 2008), for plants (Broadley et al. 2007) and for even microorganisms (Sugarman 1983) and is necessary for prenatal and postnatal growth and development (Hambidge and Krebs 2007). Zinc is the most abundant trace metal which appears in all enzyme classes (Cherasse and Urade 2017).

Zinc deficiency affects about two billion people in the developing world and is associated with many diseases (Xiao et al. 2020). In children, deficiency causes growth retardation, delayed sexual maturation, infection susceptibility, and diarrhoea (Hambidge and Krebs 2007). Enzymes with a zinc atom in the reactive center are widespread in biochemistry, such as alcohol dehydrogenase in humans (Prasad 2003).

Table 11.1 Zinc characteristics

Category	Characteristics
Appearance	Silver-gray
Atomic weight	65.38
Atomic number	30
Group	Period 4
Oxidation state	Mainly +2 (Zn^{2+})
Main isotope	^{65}Zn

11.3 Biological Functions of Zinc

The biological functions of zinc can be divided into three categories as catalytic, structural, and regulatory function (Cousins 1996). Firstly, the catalytic function of zinc involves numerous specific enzymes such as alcohol dehydrogenase and which depend on zinc for enzyme catalytic activity (Fig. 11.1). Zinc metalloenzymes appears in all six enzyme classes (Table 11.2) (Kidd et al. 1996). Zinc acts as an electron acceptor which contributes to its catalytic activity in many of these enzymes. If zinc is removed from the enzyme component that causes the loss of activity, and the reconstitution of the holo-enzyme with zinc restores enzyme activity. Therefore due to dietary zinc deficiency or excess may alter the activity of these zinc metalloenzymes, thus may affect metabolic regulation.

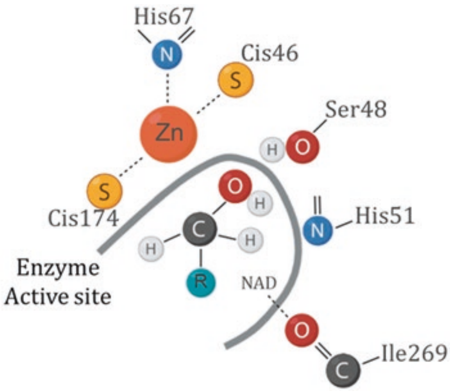

Fig. 11.1 Zn incorporated in alcohol dehydrogenase. The active site for alcohol dehydrogenase includes a zinc and various amino acids such serine (Ser), hisitidine (His), isoleucine (Ile), and cysteine (Cis). The alcohol at active site and NAD are connected to the enzyme with the isoleucine and zinc

Table 11.2 Representative zinc metalloenzymes for biological catalytic activity

Class	Enzyme
Oxidoreductase	Alcohol dehydrogenase Superoxide dismutase Malic dehydrogenase Lactic dehydrogenase
Transferase	RNA polymerase DNA polymerase Reverse transcriptase
Hydrolase	Alkaline phosphatase Carboxypeptidase A, B Collagenase
Lyase Isomerase Ligase	Carbonic anhydrase Phosphomannose isomerase tRNA synthetase

Secondly, the structural function of zinc is the case for zinc-finger transcription factor, which can form domains capable of zinc coordination and this zinc coordination facilitates protein folding to produce biologically active molecules. This particular zinc-containing protein can form a 'zinc finger-like' structure (Klug and Schwabe 1995) and have a roles in gene expression as DNA binding transcription factors, as zinc finger transcription factor. The implication of zinc finger protein bioactivity to dietary zinc is still on-going interests in study. Zinc also can serve as the structural component for some enzymes such as Cu/Zn dismutase for antioxidant activity. In this enzyme, zinc functions as a structural component, while Cu provides catalytic activity (Cousins 1996).

Thirdly, Regulatory function of zinc is that zinc works regulator in various biological process such as for gene expression, cell apoptosis, neuronal signaling etc. The most-widely studied gene expression regulation by zinc is metallothionein (MT) gene expression by metal regulartory element transcription factor (MTF)-regulated gene expression. Metallothionein (MT) as metal binding protein gene expression is regulated once zinc binds to metal response element transcription factor (MTF-1), which consequently activates MT gene transcription (Cousins 1994). MTF-1 knockout mice showed a deficit during fetal development which suggests some critical genes must be regulated by MTF-1 in which zinc may be involved as a regulator for gene expression (Cousins 1996; DRI 2000). At the gut mucosal cells, when dietary zinc is in excess then zinc upregulates MT expression to bind more zinc therefore decrease excess zinc in the cells, while dietary zinc is low in vice versa, through this regulation mechanism cellular zinc is maintained as homeostasis at absorption level at the gastrointestinal tract cells. Therefore MT protein appears to act as zinc trafficking molecule for maintain cellular zinc concentrations (Cousins 1996). For another zinc homeostasis at cellular level, zinc transport proteins ZIP and ZnT are also regulated by zinc (Cousins 1996).

11.4 Zinc in Foods and Dietary Needs

Zinc is widely distributed in various foods and particularly protein-rich meat and seafood are usually good sources of zinc. Therefore dietary zinc intake is higher in the developed countries where animal food intake level is higher than in the developing and underdeveloped countries where plant food intake level is higher. Animal-based foods for zinc intakes are such as beef, pork, lamb, oyster, cheese, yogurt etc. Oyster is good food source for zinc. Some plant-based foods also can contribute dietary zinc takes, such as nuts, seeds, beans, peas, wheat germs and whole grains etc. Refined white flour or refined grains are poor sources of zinc, therefore zinc is fortified for some breakfast cereals, but not enough for the proper zinc take (Byrd-Bredbenner et al. 2013).

Whole grains and bread which are not refined contains significant amounts of zinc as diet supply, however unleavened whole-grain bread is high in dietary fiber and phytate which bind with zinc at the gut, therefore inhibit zinc absorption at the gastrointestinal tract, consequently decrease zinc bioavailability. Fermentation by yeast may reduce the effect of phytate therefore can increase zinc bioavailability. The first human zinc deficiency was observed in Middle Asia where the people ate unleavened bread which contained high phytate therefore inhibit zinc absorption, along with low intakes of zinc rich-animal food sources (Byrd-Bredbenner et al. 2013; KDRI 2000).

Dietary needs for zinc are 10 mg/day for adult men and 8 mg/day for adult women as Recommended Dietary Allowance (RDA) level for South Koreans. The RDA is the zinc take level for the average amount needed to replace the daily losses in faeces, urine, and sweat and considered with an estimated dietary absorption of 40%. Data from Korea National Health and Nutrition Examination Survey (KNAHES) survey indicate that average zinc intakes for men and women adults in South Koreans are 12.1 mg/day and 8.7 mg/day as RDA, respectively, which currently meet RDA guidelines (KDRI 2000). Zinc intake measurement in nationwide and the data for zinc intake from the underdeveloped and developing countries are confirmed easily which makes the accurate estimation of zinc nutriture in those countries are not utilized, which may be the major concern for improper zinc nutriture in worldwide in sustainability for human health and preventing zinc deficiency-caused diseases.

11.5 Dietary Zinc Absorption, Transport, Storage, and Excretion

Zinc absorption occurs at small intestine. Dietary zinc is absorbed primarily in the duodenum and the majority of zinc is absorbed by the small intestine through a transcellular process with the jejunum being the site with the greatest transport rate (Cousins 1989; Lonnerdal 1989; Lee et al. 1989). Dietary zinc is absorbed into the gut cells by simple diffusion in zinc concentration gradient manner and active transport using ATP against zinc concentration gradient. Once zinc is absorbed into gut cells zinc induces the synthesis of metallothionein (MT), which binds zinc. At the gut cellular level, the regulation of dietary zinc absorption is regulated by the synthesis of metallothionein; it hinders the movement of zinc from intestinal cells. When excess zinc is in the intestinal lumen, then zinc is not transported out of the intestinal absorptive cell into the bloodstream but the intestinal cells are sloughed off which is mucosal block, and zinc excretes out of the body in the faeces. This is the way that decreases when zinc is excess in gastrointestinal tract.

Since zinc is metal and body elaborately regulates to keep the optimal zinc level. Like most metal nutrients, the absorption of zinc is affected by dietary components and the body's need for the mineral (Byrd-Bredbenner et al. 2013). Zinc absorption

Table 11.3 Factors for increasing and decreasing zinc absorption

Increasing zinc absorption	Decreasing zinc absorption
Low zinc intake	High zinc intake
Zinc deficiency	Optimal zinc status
Under condition increased need for zinc	Phytate
Amino acids	Dietary fiber
	High nonheme iron intake (competing Zn and Mn absorption.)

rate increases when zinc take is low thus body can keep more zinc, while it decreases when zinc intake is high so the body keep adequate zinc level. Also high intake of disturbing factors for zinc absorption such as phytate and dietary fiber may decreases zinc absorption. Factors that stimulate or disturb zinc absorption and zinc bioavailability are presented in Table 11.3.

Zinc transport across the gut cells into the blood vessel occurs in regulated manner. Once zinc is absorbed into the bloodstream, it binds to albumin, the blood protein, for transport to the liver or any other organs. The liver manufactures zinc as appropriate with other proteins, and uptakes and releases zinc into cytosol as well as into the blood. In this process, multiple zinc transport proteins are involved in the cellular uptake and release of zinc.

Zinc storage not appears in our body in general, compared to the other energy nutrients can be stored, since it is metal. Instead storing zinc in the body, the body keeps zinc level by regulating absorption or maintaining an exchangeable zinc pool which is composed of various organs such as liver, bone, pancreas, kidney and circulating blood. To keep zinc homeostasis, body utilize this exchangeable zinc pool by recycling zinc through the organs and circulation, especially when dietary zinc intake and blood zinc level are low (Byrd-Bredbenner et al. 2013).

Zinc excretion occurs mainly through the gastrointestinal tract into faeces both under normal intake level as well as excessive dietary zinc and supplement are taken, thus decrease the risk of toxicity. Also, small amount zinc is excreted through urine, sweat, body fluid and for estimating dietary reference intakes for zinc, these zinc loss are considered to make up for proper zinc intake (DRI 2000). To avoid the excess zinc intake from supplemental or environmental, the upper level for zinc for Korean Dietary Reference Intakes (KDRI 2000) is suggested as 35 mg/day for an adult, which is about 3-4 times of Recommended Dietary Allowance, 8–11 mg/day. The symptoms of zinc toxicity are loss of appetite, nausea, vomiting, diarrhoea, intestinal cramps, and often immune function is impaired. Since zinc and copper compete for absorption, excess zinc intakes also disturb copper absorption in gastrointestinal tract and copper activity in metabolism. When a person takes zinc supplement to decrease cold symptoms and other benefits of this mineral, it is good to be cause to take excess zinc intake and any potential Zn-Cu interactions.

11.6 Zinc Homeostasis by Cellular and Molecular Mechanism

To regulate zinc level at physiological and cellular level for body zinc homeostasis, zinc utilizes various zinc-related proteins: Zinc binding protein metallothionein (MT) at gut level for uptaking dietary zinc and zinc transporters, ZIP and ZnT at cellular level for importing and exporting zinc for cellular zinc level (Fig. 11.2). The cellular and molecular mechanisms controlling intracellular zinc homeostasis have been investigated zinc the discovery and cloning of zinc transporters (Palmiter and Findley 1995).

Zinc absorption is mainly from small intestine. At the gut, zinc absorption can be affected by other dietary factors, such as phytate and dietary fiber, which can decrease zinc bioavailability.

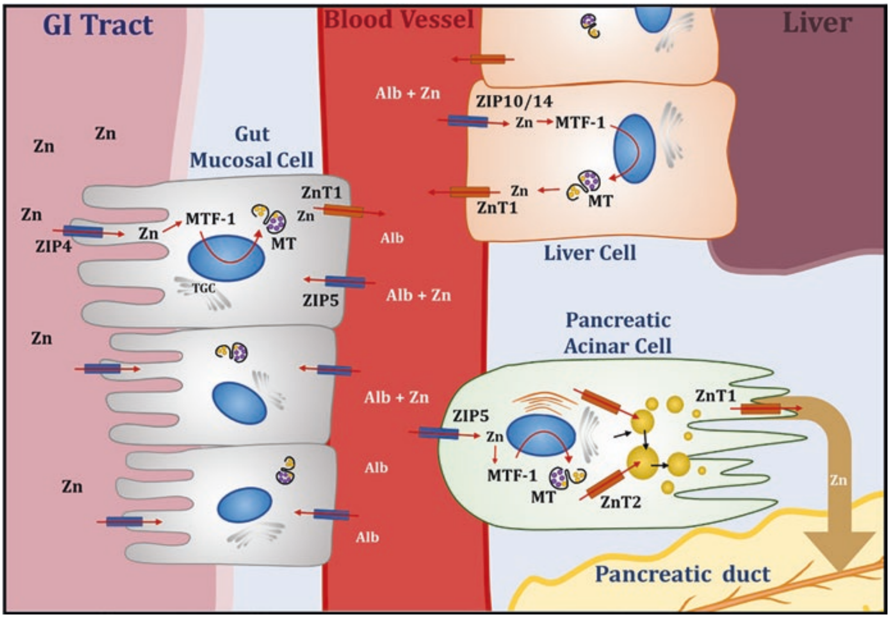

Fig. 11.2 Zinc absorption and cellular regulation for zinc homeostasis. At small intestine, zinc is uptaken across the gut mucosa cell apical membrane and this is regulated by zinc transporter ZIP4 which imports zinc inside gut cell. In mucosal cells, the amount of free zinc is regulated by zinc-binding protein metallothionein (MT) through the activation of metal-specific transcription factor, metal regulatory transcription factor 1 (MTF-1). After then, zinc is transported into the circulation and after binding with plasma protein albumin, zinc is transported mainly to the liver where it is uptaken by zinc importing transporters, ZIP10/ZIP14. Otherwise, zinc is uptaken by pancreatic cell and flux out cells by zinc exporting transporter, ZnT1 for excretion into the pancreatic duct for maintaining zinc homeostasis. Zinc homeostasis at absorption level is regulated by MT and cellular uptake and fluxing of zinc is regulated zinc transporters ZIPs and ZnTs

Zinc uptake across the gut mucosal apical cell membrane is mainly regulated by zinc transporter, ZIP4 (Beattie et al. 2018; Hara et al. 2017; Kimura and Kambe 2016). Zrt-/Irt-like proteins (ZIPs) mainly mediate the zinc influx from the extracellular or luminal side into the cytoplasm (Bin et al. 2018). There are two types of zinc transporter: ZIP imports Zinc from the extracellular or luminal side zinc into the cytoplasm, while ZnT exports zinc from the intracellular cytosol to outside cell membrane or from the intra-micro-organelle to outside cellular organelle membrane.

In the mucosal cells, free zinc is regulated by metallothionein (MT) through activation of metal transcription factor 1 (MTF-1) that induces the expression of MT. And then, zinc is transferred across the basolateral membrane by another zinc transporter ZnT1. It is a protein that in human is encoded by the MTF-1 gene (Brugnera et al. 1994; Entrez Gene 2022). MTF-1 gene encodes a transcription factor that induces expression of metallothioneins (MTs) and other genes involved in metal homeostasis in response to heavy metals such as cadmium, zinc, copper, and silver. The protein MTF-1 is a nucleus and cytoplasmic shuttling protein that accumulates in the nucleus upon heavy metal exposure and binds to promoters containing a metal-responsive element (MRE) (Entrez Gene 2022).

MT is involved in metal homeostasis in response to heavy metals including zinc. This protein is a nucleocytoplasmic shuttling protein that accumulates in the nucleus upon heavy metal exposure and binds to promoters containing a metal-responsive element (MRE) in DNA (Brugnera et al. 1994). MT is a family of cysteine-rich, low molecular weight (MW ranging from 500 to 14,000 Da) proteins. They are localized to the membrane of the Golgi apparatus. MTs have the capacity to bind heavy metals such as zinc, copper, selenium etc. through the thiol group of its cysteine residues, by which MT plays a role in the protection against metal toxicity and oxidative stress, and MT is involved in zinc and copper regulation (Felizola et al. 2014).

After zinc is imported into cells, then zinc is transferred across the basolateral membrane by another zinc transporter ZnT-1 to the blood vessel. In the circulation, zinc is bind to serum albumin, and then it is transported primarily to the liver where zinc is incorporated into hepatocytes by zinc transporters ZIP10 or ZIP14 for transportation. A majority of this hepatic zinc fluxes in and out of liver cells for cellular zinc homeostasis, therefore turnover rate of liver zinc pool is fairly rapid. Body zinc homeostasis is regulated and maintained through all these various zinc-relating proteins (MT, ZIP and ZnT) and key cells (gut, liver and pancreas) for sustaining the optimal zinc level as well as avoiding metal toxicity.

11.7 Zinc Deficiency in Human Health

Zinc deficiency is a major health concern in many parts of the world where poverty limits food supply and choices. It is more prevalent in children and pregnant and lactating women. Various studies conducted over years have provided evidence that zinc deficiency is a worldwide public health problem (Caulfield and Black 2004; IZiNCG 2004; Walker et al. 2009).

World Health Organization (WHO) estimates that zinc deficiency affects 31% with the prevalence rates ranging from 4% to 73% in various regions of the world's population (Caulfield and Black 2004). In developing countries zinc deficiency is one of the ten significant factors contributing to burden of disease (Khalid et al. 2014). According to a report on global and regional child mortality and burden of disease attributable to zinc deficiency, Africa suffers 58% of child deaths attributable to zinc deficiency. Ethiopia is one of the five countries who together contribute 47% of the child deaths attributable to zinc deficiency in Africa (Walker et al. 2009). According to Ethiopia Demographic and Health Survey (EDHS) 2011, nearly 44% of the under-five children are stunted. Stunting in children is considered as an indirect indicator of zinc nutritional status (IZiNCG 2004).

Severe diarrhea is the typical sign of severe zinc deficiency in low-economic country. The mechanism by which zinc deficiency causes diarrhea has not clarified yet. The small intestine is the major site of zinc absorption and the gastrointestinal tract is the route of zinc excretion. Dietary zinc deficiency or any conditions that decrease zinc absorption or increase zinc losses from the gastrointestinal tract may cause zinc deficiency due to the limited zinc availability of rapidly exchangeable zinc pools in the body. Diarrhea is both a sign and a cause of zinc deficiency, and zinc supplementation can lessen diarrhea (Semrad 1999).

The typical symptoms of zinc deficiency are as follow:

- growth retardation
- imcomplete sexual
- loss of appetite
- delayed wound healing
- dysfunction of immune system
- decreased taste sensitivity
- severe dermatitis (Acrodermatitis Enteropathica - *a genetic disorder of zinc metabolism)*
- severe diarrhea
- cognitive impairment
- impaired glucose tolerance

Zinc deficiency during pregnancy has an adverse effect on both mother and on subsequent birth outcomes. Particularly zinc deficiency in children and pregnant are as follow:

- pregnancy-induced hypertension
- increased risk of abortion
- miscarriage
- stillbirths
- preterm labor
- postpartum hemorrhage and prolonged labor
- low birth weight
- delayed development of immune system
- birth defects
- increased infant mortality

Poor zinc status also can impair the integrity of zinc-involving structural proteins in cells, zinc fingers and membrane receptor proteins, and as a results these zinc-proteins cannot perform properly their functions (Cassander et al. 2017). In the developed countries, overt zinc deficiencies are not common but a mild and marginal zinc deficiency is more in attention specially observed in young children, malabsorption patients, kidney dialysis patients, the hospitalized patients and vegetarians who have the restriction for animal food sources. At the present, zinc biomarkers to measure changes which reflect in zinc status are lacking, therefore detecting marginal zinc deficiency is not easy and the symptom of mild zinc deficiency also doesn't show specific symptoms. Efforts to finding more sensitive ways for zinc measurement are still on-going.

11.8 Zinc Dysregulation and Diseases

While zinc deficiency due to insufficient zinc intake from foods, therefore it impairs growth and development in biological aspects, many studies are also focused on how zinc affects for maintaining human life and disease. To investigate this mechanism, the scientists use the animal and cell model along with human subject study as it is available and the study design implies to figure out zinc role at physiological, cellular and molecular aspects. The accumulated study results showed zinc dysregulation is involved with various human chronic diseases such as immune malfunction, neuronal disease, diabetes, cardiovascular disease, even with cancer and obesity, and all these diseases are the consequences for aging process. In this part of chapter, we provide a review of the diseases affected by zinc dysregulation.

11.8.1 Impaired Immunity

The immune system is the first candidate whose function depends on and immune system can be impaired with zinc deficiency. Zinc is closely related to innate and adaptive immune response and zinc signals in lymphocyte development were clarified (Feske et al. 2015). The impaired zinc homeostasis due to dietary zinc deficiency is associated with chronic inflammation (Foster and Samman 2012; Penny 2004). The impaired immunity can develop respiratory, gastrointestinal and other infections, such as from common cold, flu and up to pneumonia (Foster and Samman 2012). Under zinc deficiency, the blood levels of inflammatory cytokines (IL-1β, IL-2, IL-6, TNF-α etc.) are affected and zinc supplementation showed a dose-dependent response in the level of inflammatory cytokine. The impact of zinc on the immune system is especially well documented in the elderly whose group having zinc deficiency in common condition (Maywald and Rink 2015). Children and elderlies are susceptible to zinc deficiency, consequently the immune function in these group are needed to be in special concern for optimal immunity function.

11.8.2 Neurodegenerative Disease (Alzheimer's Disease and Parkinson's Disease)

The roles of zinc in neurodegenerative and neurodevelopmental disorders are of interests in many years and recently the increasing body of data indicates the potential involvement of zinc metabolism in neurodegeneration. Actually the influence of zinc homeostasis in the incidence, prevalence and treatment of neurodegenerative diseases, such Alzheimer's disease and Parkinson's disease is one of the most studied and discussed subjects in zinc research area (Beattie et al. 2018). Zinc acts as neuromodulator at neuronal excitatory synapses and showed the function of zinc-dependent enzymes which contributed to maintain brain compensatory capacity (Frederickson et al. 2005). Therefore, it is not surprising that dysregulated zinc homeostasis has been implicated in neurodegenerative diseases, Alzheimer's disease and Parkinson's disease. The regulation of zinc homeostasis in the brain is under the control of zinc-binding protein, metallothionein (MT) and zinc transporter proteins, ZIPs and ZnTs and the study reports that the brain specific MT isoform seems to be particularly affected by aging, showing a higher increase in a aging rat model, which implies aging-related neural degeneration would have the relation with zinc status in elderly people (Scudiero et al. 2017). Systemic zinc levels in Alzheimer's and Parkinson's disease were found to be reduced, whereas zinc sequestration in brain may result in modulation of amyloid-β and α-synuclein processing with subsequent toxic effects (Skalny et al. 2021). Zinc dysregulation as well as aging would be the risk factors for neurodegenration in elderly people.

11.8.3 Diabetes Mellitus

Dysregulated zinc homeostasis is commonly observed in diabetes mellitus type 2 patients and its complications, which implies that zinc has the role in systemic glucose regulation. Zinc dysregulation is related to the impaired glycemia and diabetes which can be explained by physiological role in insulin-receptor signal transduction (Hasse and Maret 2005), insulin storage and secretion (Figlewicz et al. 1984). Meta-analysis results demonstrated that low serum zinc level and the increased urinary zinc excretion is associated with poor glycemic control in patients with diabetes mellitus 2 patients (da Silva Bandeira et al. 2017) and in human subject study, serum zinc levels are adversely associated with glucose and HbAlc levels (Skalnaya et al. 2017), and lower serum zinc levels and insulin resistance in prediabetic women is associated (Skalnaya et al. 2018). At cellular level, wide genome association study demonstrated the association of a polymorphism in the coding region of zinc transporter ZnT-8 gene (SLC30A8) with the susceptibility to diabetes mellitus 2 patients (Fan et al. 2016). As benefit of zinc role in glucose regulation is accumulated in large amount from the cellular, animal and human subject studies, zinc can be further investigated as the potential therapeutic biometal for glucose control for diabetes.

11.8.4 Cardiovascular Disease

The study for zinc effect on cardiovascular disease has been interests of to investigate, since cardiovascular disease is common as being aging (Beattie and Kwun 2004). The increasing numbers of studies have been supported that the association between zinc deficiency and cardiovascular diseases (Little et al. 2010; Beattie et al. 2012). A meta-analysis shows that a significant association between low serum zinc levels and heart failure (Yu et al. 2018). Another meta-analysis also shows that zinc deficiency is associated with myocardial infarction (Liu et al. 2015). When zinc is supplemented, then blood lipid markers such as total cholesterol, LDL cholesterol and triglycerides decreased which implies the beneficial effect of zinc in cardiovascular disease including atherosclerosis (Ranasinghe et al. 2015).

One of the mechanisms that zinc improves high lipid profiles and prevents cardiovascular disease is zinc involvement in the nitric oxide (NO), more in details, zinc is needed for the dimerization of endothelial NO synthase and therefore NO production in blood vessel (Zalewski et al. 2018). Our group reported that zinc deficiency regulates cell proliferation and apoptosis of vascular smooth muscle cells would be the reason for the cardiovascular disease (Allen-Redpath et al. 2013, Alcantara et al. 2013). In our work, under zinc deficiency vascular smooth muscle cells showed more apoptosis and that could be related to the production of a novel discovered zinc-regulated factor (Ou et al. 2013). When primary rat vascular smooth muscle cells were treated with plasma from zinc-deficient rats, showed increased apoptosis (Allen-Redpath et al. 2013), and the changes in genomic expression are mediated by a low molecular weight (about 2 kDa) humoral factor which was affected by zinc deficiency (Ou et al. 2013). Our set of studies showed that zinc deficiency causes vascular smooth muscle cell apoptosis which may contribute to the development of the cardiovascular disease during zinc deficiency. Investigating of these mechanisms would lead to the development of new therapeutic approach of zinc to prevent and to treat cardiovascular disease as well cardiac disorders. Recent review summarize zinc role in exercise and proteostasis which implies for the additional benefit of zinc function in maintaining human health and preventing the disease for aging (Hernandez-Camacho et al. 2020).

11.9 Conclusion

In this chapter, we reviewed characteristics, biological function, homeostasis mechanism, cellular and molecular regulation of zinc and especially emphasized zinc deficiency health and various diseases. Research findings for zinc function in various diseases and its cellular and molecular mechanism significantly expanded the understanding of the role of zinc in immunity, neurodevelopmental and neurodegenerative disorders, diabetes, cardiovascular disease and even to obesity and cancer, and support the use of zinc in various chronic diseases (Skalny et al. 2021). All these recent advances in zinc research in biology and medicine support the importance of zinc in human health and disease prevention.

These findings are of importance especially in view of still persisting high risk of zinc deficiency in low economic countries and mild/marginal zinc deficiency in high economic countries. Further laboratory studies about zinc role in human health and disease should focus on the particular mechanisms of the role of altered zinc homeostasis in diseases and how zinc can regulate the mechanism to prevent diseases. Additionally, human studies should be designed in order to obtain high-quality systematic data on therapeutic approach of zinc to provide evidence-based support for the use of zinc in the management of various diseases.

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Chapter 12
Tackling Hidden Hunger: Understanding Micronutrient Deficiency and Effective Mitigation Strategies

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12.1 Introduction

Micronutrient deficiencies, known as hidden hunger, caused by lack of essential vitamins and minerals, are major global health concern and can lead to various illness and deaths. Approximately one-third of the global population is affected by these deficiencies (HLPE 2017). The 2020 Global Nutrition Report highlighted significant disparities in the prevalence of micronutrient deficiencies, particularly in low- and middle-income countries (GNR 2020). Micronutrient deficiency is a serious issue in both developing and developed countries, as evidenced by the increase of the number of malnourished people worldwide over the past few years. In 2021, 828 million people globally faced hidden hunger as estimated by FAO. The prevalence of malnourishment in the world increases from 8% to about 9.3% in 2020, and then further to 9.8% in 2021 (fao.org). One strategy for addressing the problem of micronutrient deficiencies and improving the intake of essential vitamins and minerals is food diversification. This approach seeks to increase the availability and acceptability of a wider range of foods, particularly for the nutritionally vulnerable sections of population, thereby better access to adequate micronutrients Other strategies include food fortification (Sirohi et al. 2018), appropriate dietary mix, and public health measures like immunization and infection control (Hélène 2003).

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12.2 Consequences of Micronutrient Deficiency

Micronutrient deficiencies have a global impact, with particular vulnerability observed among children and pregnant women. A common form of deficiency is vitamin A, which can be fatal for half of those affected within a year of losing their eyesight due to it (WHO 2009). Although data on zinc deficiency is limited, it is believed to impact more than 20% of children in low- and middle-income countries (LMICs) and is a significant health concern for children in these regions due to lack of information (Greffeuille et al. 2021). Universal salt iodization has been successful in reducing iodine deficiency globally, but mild to moderate forms still persist in 25 countries and continued efforts are necessary to ensure adequate iodine intake, especially in those countries where iodine deficiency remains a problem (Pearce et al. 2016). Folate deficiency is also a significant issue, and is associated with approximately 260,100 neural tube defect including stillbirths and neonatal deaths. The prevention of folate deficiency through diet and supplementation is crucial to reduce the burden of these conditions (Blencowe et al. 2018). Anaemia is prevalent, affecting 41.6% of children and 32.6% of women of reproductive age globally and while iron deficiency is a major cause contributor, other factors such as nutrient deficiencies, infections, and genetics may also play a role (GNR 2018; Petry et al. 2016). The implications of micronutrient malnutrition are significant for health and economic prosperity of nations. Although it contributes a small portion to the total global burden of disease, its effects are far-reaching and can lead to long-term health problems, decreased productivity, and increased healthcare costs (Horton et al. 2008; Bhutta et al. 2013; Bhutta and Haider 2009; Darnton-Hill 2012). Identifying locations where deficiencies are most prevalent and how they are evolving can enable policymakers and public health officials to prioritize interventions and allocate resources towards improving the nutritional status of populations (Han et al. 2022). In 2019, the maximum age-standardized prevalence rate of Iodine, Iron, and Vitamin A deficiency per 100,000 individuals is depicted in Table 12.1.

12.3 Measures to Overcome Micronutrient Deficiencies

Several strategies have been adopted to address the micronutrient deficiencies as depicted in Fig. 12.1. WHO and FAO have outlined four key strategies to combat micronutrient deficiencies. These strategies include nutrition education to encourage diverse and healthy diets, food fortification to enhance commonly consumed foods with micronutrients, vitamins and minerals supplementation, and disease control measures to prevent malnutrition resulting from infections. Implementing these strategies could have a positive impact on the health and well-being of population worldwide (Allen et al. 2006). As we mentioned earlier, infants, young children, and women of reproductive age are the sections most affected by micronutrient deficiencies. Providing multiple micronutrient supplements during pregnancy can increases birth weight and reduce the incidence of low birth weight babies, while

Table 12.1 The highest global age-standardized prevalence rate of Iodine, Iron, and Vitamin A deficiency in the year 2019 per 100,000 people

S. no.	Micronutrients name	Countries affected	Prevalence rate	Gender affected	Age
1.	Iodine	Somalia Democratic Republic of the Congo Djibouti Republic of the Congo	(21,101 [17,356–24,960]) (16,385 [13,383–19,590]) (13,295 [10,704–16,391]) (11,189 [9051–13,535])	Higher in females than in males	30–34 years
2.	Iron	Bhutan Zambia India	(32,086 [34,028–30,283]) (29,784 [27,774–31,630]) (28,344 [27,754–28,888])	Higher in females than in males	All age groups
3.	Vitamin A	Somalia Niger Micronesia Chad	(63,640 [59,280–67,658]) (43,502 [38,968–48,083]) (34,769 [30,794–38,842]) (34,261 [29,898–38,896])	Higher in males than in females	1–4 years

Source: Han et al. (2022)

such supplementation among young children could improve growth, haemoglobin, serum retinol and Zn levels as well as motor development (Imdad and Bhutta 2012; Suchdev et al. 2012).

12.3.1 Dietary Diversity

Ioniţa-Mîndrican et al. (2022) suggested that dietary diversity can improve child nutritional outcomes and long-term dietary diversification can ensure a diet with an adequate and balanced ratio of macronutrients (carbohydrates, fats, and protein), micronutrients (vitamins and minerals), and other food-based compounds including

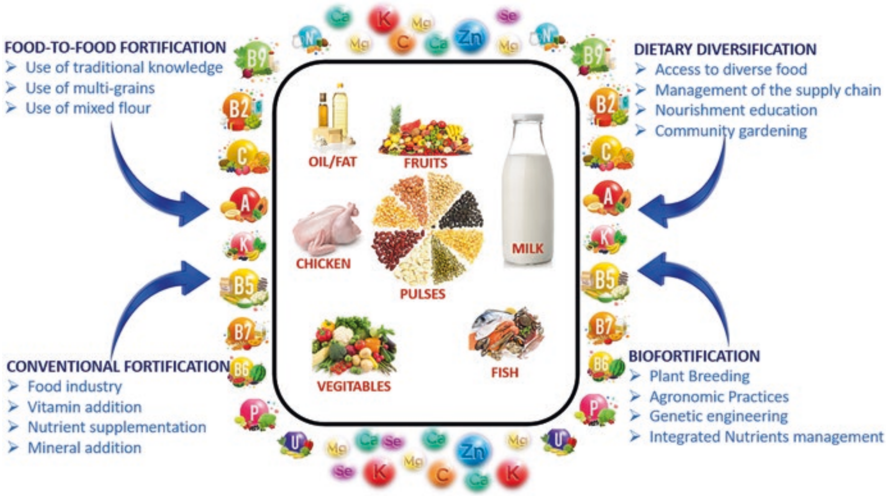

Fig. 12.1 Strategies to combat micronutrient deficiency

dietary fibre. While most people can obtain adequate nutrition from a range of cereals, legumes, fruits, vegetables, and animals-based foods, certain groups, such as pregnant women, may require supplements. Food-based interventions, including home gardening and education on improved infant and young child feeding practices, food preparation, and storage or preservation techniques to minimize nutrient loss, are effective approaches to enhance dietary diversity (WHO 2018; Di Prima et al. 2022). Furthermore, dietary diversify can also expand the scope of intake of various bioactive compounds such as antioxidants and probiotics, which are essential for enhancing immune system function and preventing certain non-communicable diseases (Chaturvedi et al. 2022). However, increasing dietary diversity can be challenging due to need for behaviour modification and education on the role of specific foods in supplying important micronutrients and other nutrients. In resource-limited communities, a lack of resources for growing and obtaining higher quality foods can also be a significant barrier to achieving greater nutritional diversity. Animal source foods are becoming increasingly important for dietary quality, and innovative strategies for improving their production and consumption in less developed countries are investigation. Providing breast milk as a primary source of nutrition for young children is an efficient strategy for preventing micronutrient-deficiencies (Wahed et al. 2022; Dipa et al. 2023).

12.3.2 Food Fortification

Many countries, including Brazil, Chile, Mexico, South Africa etc., implemented food fortification as a national program (Kimura 2013). Globally, as well as in India, food fortification is recognized as an effective tool for managing micronutrient deficiencies (Sirohi et al. 2018). While there are numerous food fortification programs worldwide, we will highlight a few noteworthy examples.

Salt Fortification with Iodine Salt has been widely used as a successful carrier for iodine fortification to combat iodine deficiency worldwide. Two main chemical forms of iodine salts used for fortification are sodium and potassium salts of iodates and iodides with fortification levels range from 30 to 200 ppm. However, according to the WHO, under normal circumstances, there is 20% loss of iodine from salt during both the manufacturing process and cooking before consumption. The average daily salt intake is around 10 g per person (Vatandoust and Diosady 2022). To address the dual problem of iron and iodine deficiencies, the National Institute of Nutrition, Hyderabad developed Iron Fortified Iodized Salt (IFIS, also known as Double Fortified Salt-DFS) (McDonald et al. 2022).

Wheat Flour Fortification with Iron Fortification of staple grains is a logical approach as they are consumed regularly and in large quantities. Several countries have enriched wheat flour with iron and other minerals. However, concerns have been raised about the bioavailability of iron in wheat atta due to its high phytate concentration, which is an absorption inhibitor. To address this issue, Na-Fe-EDTA and enzyme phytase are potential molecules that may be used to overcome phytate's inhibitory effect (Subroto et al. 2023). The higher expense of this salt may be offset by enhanced bioavailability leading to a lower required dose for fortification purposes. Rice is the staple food for more than half of India's population. Rice fortification has been attempted through the combination of fortified extruded grains from rice flour with rice (*Ultra rice*) (Mangaraj et al. 2023). However, more advanced technologies are required for rice fortification. Vegetable oil is used to attach powdered vitamin A to sugar crystals. Vitamins are sprayed on rice kernels, which are then coated with food-grade resins to prevent the vitamins from leaking when the rice is rinsed before cooking. Alternatively, simulated kernels can be produced using methods similar to those used for making noodles. In this case, the vitamins and minerals are combined with the flour used to make the simulated kernel (Boriboonkaset et al. 2013).

Cereal Products Fortification with Folic Acid Many countries fortify cereal products with folic acid to lower the occurrence of neural tube abnormalities. Folic acid supplementation, maybe in conjunction with vitamin B12, may lower serum homocysteine levels (Ismail et al. 2023).

Milk Fortification with Vitamin D The addition of vitamin D to milk, which began in the 1930s in Canada and the United States, is largely attributed to the near eradication of childhood rickets in the developed world. A recent study of African American women found that a low intake of vitamin D fortified milk was a strong predictor of a high incidence of vitamin D insufficiency (Ames et al. 2021). Milk fortification with vitamin D lowers the incidence of osteoporosis among the elderly, especially in regions with higher latitude where there is less ultraviolet light exposure during the winter months (Schwab 2011).

By implementing government policies and programmes that aim to increasing the production and accessibility of vitamin- and mineral-rich foods, coupled with marketing and educational activities that promote consumption of these foods, several countries, including India, have successfully addressed micronutrient associated malnutrition (Anand et al. 2014; Sirohi et al. 2018; Barbour et al. 2022).

12.4 Focussing Some Predominant Types of Micronutrient Deficiencies

12.4.1 Iron Deficiency

Iron is essential for cellular functions like oxygen transport, storage, and energy transfer. A lack of dietary iron can lead to tissue-level deficiencies and eventually anaemia, which can have severe clinical consequences. However, anaemia is not a reliable indicator of iron deficiency, as it may have multiple causes (Bouis et al. 2012). Infants and pregnant women are highly vulnerable to iron deficiency disorders due to their high iron requirements for growth and development. Iron deficiency during these stages can have serious consequences for both the mother and child, making it crucial to ensure sufficient iron intake (Preziosi et al. 1997). Although chronic iron deficiency anaemia is not typically a direct cause of death; moderate or severe cases can lead to hypoxia (lack of oxygen), which can worsen underlying pulmonary and cardiovascular disorders. This can ultimately lead to death, highlighting the importance of addressing iron deficiency anaemia (Horwich et al. 2002). Iron deficiency can have long-term effects on individuals whose diet primarily consists of staple food crops with little meat intake or who are frequently exposed to infections that cause blood loss. This can result in chronic iron deficiency, affecting their health throughout life (Zimmermann et al. 2005). Anaemia is a widespread problem affecting 1.62 billion people globally regardless of income level, due to inadequate nutrient intake (Pasricha et al. 2013; Branca et al. 2014). Iron deficiency, resulting from insufficient intake, absorption, utilization, or excessive losses, contributes significantly to this issue (Pena-Rosas et al. 2015). Non-pregnant women, pregnant women, and young children under five are the most affected groups, with around 29% (496 million), 38% (32 million), and 43% (273 million) respectively. However, the prevalence rates vary significantly based on socioeconomic and geographic factors (Stevens et al. 2013).

12.4.1.1 Consequences of Iron Deficiency on Health and Economics

Anaemia's high prevalence causes significant health impacts such as mortality, low birth weight, and reduced cognitive function, leading to economic losses, reduced productivity, and earnings (Pasricha et al. 2013). Iron deficiency may not show symptoms in its early stages, but it can still have functional consequences, including increased mortality rates for mothers and infants, low birth weight, impaired cognitive function, reduced work capacity, and poorer educational achievement. These impacts can have significant economic consequences for families and communities (Beard et al. 1996; Khan et al. 2006; Horton and Ross 2003). In 10 low- and middle-income countries (LMIC), the median annual economic loss due to iron deficiency anaemia was estimated at $16.78 per capita or 4% of the gross domestic product in 1994 US dollars (Pasricha et al. 2013). Anaemia, regardless of its cause, can lead to a significant reduction in productivity in heavy manual labor (17%) and a loss of earnings estimated to be between 2.5% and 4% (Horton 2006). Addressing anaemia in women in low- and middle-income countries, particularly during pregnancy, is an urgent and ongoing need (Darnton-Hill and Mkparu 2015). In populations with a high infectious burden and systemic inflammation, there is an increased risk of iron loss, which can lead to reduced absorption and utilization of iron. This makes it even more important to address anaemia in these populations, particularly in women during pregnancy when the demand for iron is high. (Prentice et al. 2007).

12.4.1.2 Strategies to Reduce the Iron Deficiency

Increasing the iron content and bioavailability of iron in the diet can be achieved through dietary modification and diversification. Some examples of dietary changes include consuming iron-rich foods and pairing them with foods that enhance iron absorption, such as vitamin C-rich fruits and vegetables (FAO 2011). Other strategies to reduce and treat iron deficiency and iron-deficiency anaemia include preventive or intermittent iron supplementation through tablets, syrups, or drops, fortification of staple foods with effective iron compounds, and biofortification (WHO/FAO 2006). Mass large-scale fortification of staple foods is a strategy to prevent the risk of developing iron deficiency and to treat pre-existing iron-deficiency anaemia by adding effective iron compounds to these foods (Peña-Rosas et al. 2014). Iron fortification of foods is often combined with other micronutrients, such as folic acid, vitamin B12, and vitamin C, to increase its effectiveness in preventing and treating iron deficiency and anaemia (Zimmermann and Hurrell 2007). This approach can be either mass-targeted or market-driven to increase iron intake in populations with high prevalence of anaemia (WHO/FAO 2006,). Iron fortification can be implemented in various food items, including soy sauce, fish sauce, salt, milk, sugar, beverages, bouillon cubes, maize flour, etc. This approach can be either mass-targeted or market-driven to increase the intake of iron in populations with a high prevalence of anaemia (WHO/FAO 2006). Recent studies have shown that iron fortified milk is associated with improved iron status, increased hemoglobin levels, and reduced anaemia in pre-schoolers (Largueza et al. 2023). Fortifying flour with micronutrients has also been shown to reduce anaemia prevalence significantly. This supports the efficacy of mass food fortification as a viable intervention to address the issue of anaemia in LMICs (Barkley et al. 2015). Deworming can be effective in reducing anaemia when combined with other interventions, such as malaria control measures. By reducing worm infections, deworming can increase the effectiveness of interventions that aim to increase iron intake, ultimately leading to a reduction in anaemia prevalence (Spottiswoode et al. 2012). The WHO and UNICEF jointly recommended an integrated approach to address anaemia, including iron supplementation, fortification of food with iron, treating underlying health conditions, dietary diversification, improved sanitation and access to clean water, improved access to healthcare, and educating consumers about nutrition. This approach aims to tackle anaemia from various angles and promote overall health and well-being (WHO 2015b). However, despite efforts to combat anaemia, including various interventions and recommendations, global prevalence has not decreased significantly since 1995. From 1993 to 2013, the global prevalence of anaemia only decreased by 0.02–0.3% per year (Branca et al. 2014). The World Health Organization (WHO) has set a goal to reduce anaemia in women of reproductive age by 50% from the 2011 prevalence by the year 2025 (WHO 2012).

12.4.2 Iodine Deficiency

Goiter, resulting from iodine deficiency, has been documented since ancient times. Iodine deficiency is the most common cause of impaired mental development and brain damage (Hetzel 2005). Iodine deficiency leads to reduced thyroid hormone production and a range of physiological effects, resulting in iodine deficiency disorders (IDDs) such as goiter, intellectual impairments, growth retardation, neonatal hypothyroidism, and increased pregnancy loss and infant mortality. These disorders can have severe consequences on the health and development of individuals and populations, making iodine intake crucial for optimal health (Zimmermann and Boelaert 2015). Before widespread salt iodization in low- and middle-income countries (LMICs), iodine deficiency was a public health problem in most countries. While considerable progress has been made through salt iodization programs, many LMICs still face iodine deficiency issues. Addressing this problem is crucial to prevent the negative health consequences associated with iodine deficiency disorders (IGN 2015).

12.4.2.1 Consequences of Iodine Deficiency on Health and Economics

Iodine deficiency is the leading preventable cause of mental retardation worldwide. It can be especially harmful during early pregnancy and childhood, as it can lead to serious consequences such as stillbirth, miscarriage, and increased infant mortality.

If left untreated, severe iodine deficiency can cause a condition called cretinism, a condition characterized by severe physical and mental developmental delays. Addressing iodine deficiency is crucial for preventing these negative health outcomes (Hetzel 2005; Zimmermann and Boelaert 2015). Mild iodine deficiency can result in a significant loss of learning ability, ranging from 8 to 15 IQ points (Rohner et al. 2014; Bleichrodt and Born 1996; Christian et al. 2015). Iodine deficiency can lead to a loss of significant economic productivity. The World Bank has estimated that investing one US dollar in preventing iodine deficiency disorders would yield a productivity gain of US$28. This highlights the potential economic benefits of addressing iodine deficiency through measures such as salt iodization (Hetzel 2005).

12.4.2.2 Strategies to Reduce the Iodine Deficiency

Significant progress has been made in the last few decades in addressing iodine deficiency through salt fortification. The percentage of households consuming adequately-iodized salt in the developing world has increased from less than 20% in 1990 to over 74% today, indicating a significant improvement in the availability of iodine in diets (UNICEF 2015). Over the years, the number of countries classified as iodine deficient has dropped from 110 in 1990 to 25 in 2015, indicating a significant decrease in iodine deficiency (IGN 2015). Even though there has been significant progress in salt iodization, iodine deficiency is still a major public health issue in both developed and developing countries, where the consumption of iodized salt or other iodine-rich food sources is inadequate or inconsistent (Pearce et al. 2013). Although progress has been made in preventing iodine deficiency through salt iodization, a significant proportion of households, accounting for around 26%, in low- and middle-income countries still do not consume iodized salt. Furthermore, 25 countries are still considered iodine-deficient, although none are considered severely deficient. Iodine deficiency is defined as having a median urinary iodine concentration below 100 µg/L; with 18 countries mildly deficient and 7 countries moderately deficient (The World Bank 2015; IGN 2015).

12.4.3 Vitamin A Deficiency

People who live in poverty are more likely to experience vitamin A deficiency (VAD) as they tend to have limited access to nutritious foods, especially those rich in retinol, which is more expensive. Consuming poor-quality diets with limited access to bioavailable retinol-rich sources increases the risk of developing VAD as a public health problem (Sommer and West 1996). Beta-carotene is a form of provitamin A that is found in plant sources like fruits and vegetables. It needs to be converted to active vitamin A in the body, and this process is not very efficient. Therefore, beta-carotene is much less bioavailable than preformed vitamin A found in animal sources like liver, eggs, and milk (Tanumihardjo 2011). According to the

1995–2005 estimates by the World Health Organization (WHO), 122 countries were identified as having moderate to severe public health problems due to low serum retinol levels (below 0.70 μmol/L) in preschool-age children. Additionally, 88 countries were classified as having a problem of moderate to severe public health significance due to biochemical vitamin A deficiency in pregnant women. Young children and pregnant or lactating mothers are the most vulnerable to vitamin A deficiency (WHO 2009). During the last trimester of pregnancy, both the unborn child and the mother have a high demand for vitamin A, making them particularly vulnerable to deficiency (WHO 2015a, b). An estimated 190 million preschool-age children and 19.1 million pregnant women globally have low serum retinol concentration, which corresponds to 33.3% of the preschool-age population and 15.3% of pregnant women at risk of VAD worldwide. Africa and South-East Asia are the most affected regions for both groups, with the highest prevalence found in sub-Saharan Africa. These vulnerable groups require targeted interventions to improve their vitamin A status and prevent adverse health outcomes (WHO 2009). There are challenges in accurately estimating VAD, including the need for more recent national surveys, identifying the best biomarkers and their relationship to coexisting infectious diseases, and understanding the body's mechanisms regulating vitamin A (Tanumihardjo 2011).

12.4.3.1 Consequences of Vitamin A Deficiency on Health and Economics

Vitamin A Deficiency (VAD) can lead to blindness in children, specifically xerophthalmia. VAD also causes anaemia and weakens immunity in children, increasing their susceptibility to infectious diseases. As a result, these diseases become more severe and increase the risk of mortality in young children by almost 25%. Inadequate intake of vitamin A due to poor diets, combined with a high prevalence of infectious diseases and poor environmental conditions, result in low body stores of vitamin A. This leads to a deficiency in meeting the physiological needs of the body for supporting tissue growth, normal metabolism, and immunity against infections (Tanumihardjo 2011; WHO 2015a, b). Every year, between 250,000 and 500,000 vitamin A-deficient children suffer from blindness, and around 50% of them die within 12 months of losing their sight. Globally, night blindness is a common early sign of vitamin A deficiency and is estimated to affect 5.2 million preschool-age children (with a confidence interval of 2.0–8.4 million) and 9.8 million pregnant women (with a confidence interval of 8.7–10.8 million) (WHO 2015a, b).

12.4.3.2 Strategies to Reduce the Vitamin A Deficiency

Reduced immunity against infectious diseases is the main reason why Vitamin A Deficiency (VAD) is such a serious public health issue, and why it has gained global attention. Supplementation with high doses of retinol two to three times a year to children aged 6–59 months has been a crucial public health intervention, which has received considerable funding from organizations like the Canadian government through the Micronutrient Initiative. However, high-dose supplementation alone does not lead to lasting improvements in vitamin A status. Therefore, it is necessary to implement complementary measures such as improving diets through home gardening, especially in female-headed households, and addressing infectious diseases. These measures are essential for long-term improvement in vitamin A status and for reducing the incidence of VAD-related blindness and mortality in children. It is important to note that tackling VAD requires a multi-sectoral approach and coordination between different actors and stakeholders, including governments, NGOs, and communities (Talukder et al. 2000). Addressing vitamin A deficiency requires a combination of nutrition education to change dietary habits and providing better access to vitamin A-rich or provitamin A (beta-carotene) foods, whenever possible. These foods include most orange-fleshed fruits such as mangoes, and papaya, or vegetables like the biofortified orange sweet potato, as well as dark green leafy vegetables. Encouraging home gardening or local cooperatives to grow such foods has had considerable success, including in empowering women in some settings such as Bangladesh, and sweet potato biofortification in southeast African countries. Nutrition education helps individuals understand the importance of consuming a diverse and nutritious diet, including vitamin A-rich foods, while home gardening and local cooperatives can increase access to these foods in communities. Biofortification, which involves increasing the nutrient content of crops through plant breeding, can also help address vitamin A deficiency. These strategies are essential for improving vitamin A status, especially in areas where high-dose vitamin A supplementation is not feasible or sustainable. A comprehensive approach that integrates nutrition education, home gardening, and biofortification has the potential to sustainably reduce the burden of vitamin A deficiency and its associated health consequences (Palmer et al. 2017). Fortification, which involves adding nutrients to staple foods, has only recently been considered as an option for low- and middle-income countries (LMIC). There is concern about the sustainability of national supplementation programs if donor support is withdrawn. Additionally, fortification is considered a more effective and physiologically appropriate strategy as it provides a regular intake of smaller quantities of nutrients compared to high-dose supplementation (Mason et al. 2014, 2015). In Central and South America, fortification of staple food or condiment with vitamin A has been the primary strategy for reducing vitamin A deficiency (VAD) over the past three decades. Sugar was one such food that began to be fortified with vitamin A, and this approach has been successful in increasing dietary intake of the vitamin and reducing the prevalence of VAD in these regions (Mora et al. 2000).

12.5 Conclusion

Micronutrient deficiency is a major challenge in ensuring global food security. Over two billion of the world population suffers from the micronutrient deficiency on a rough estimation. Majority of the micronutrient deficiency can be attributed to lack of iron and vitamin A in the food. The hidden hunger of micronutrient deficiency has varying effects on human population. The morbidity, mortality and severity of effect differ on the basis of age, sex and health conditions. Marginalized people in the third world nations are always at stake due to not just scarcity of access to food. The WHO has suggested for an integrative approach for abatement of the problem of the micronutrient deficiency by amalgamation of traditional knowledge and practices for nutrition management with the modern techniques for crop improvement and agronomic methods. Besides, food fortification, biofortification through genetic engineering and molecular-assisted-selection of improves crop plants also could play vital roles in mitigating hidden hunger. Universal acceptance of fortified foods should be improvised and the governmental policies should be so framed so as to ensure not just food security but nourishment security to all.

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Part V
Functional Foods

Chapter 13
Functional Food in Promoting Health: Global Perspective

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13.1 Introduction

Recent rechearch has shed light on how food ingredients impact our physiological functioning and overall health. A correlation between diet rich in nutritional value and the associated health benefits, is making functional foods (FF) an area of interest for both researchers ans well as consumers. The foods with great nutritional value, known as functional foods, exhibit immediate and long-term health benefits and lowering the risk of chronic diseases (Arshad et al. 2021). The origin of the term 'functional food' can be traced back to Japn in the early 1980s (Bellisle et al. 1998). While there is no universally accepted definition of functional foods, a common and straightforward explanation is that the processed foods that provide disease preventing and/or health-promoting benefits beyond their nutritional value. Functional foods often share similarities with different categories of foods such as nutraceuticals, medicinal food, pharmafoods, vitafoods, etc., to mention a few. However, the acceptance of functional foods by consumers depends on their interest in and confidence in these products. Therefore, accurate communication of the health benefits of these products and a supportive regulatory environment for their approval and associated health claims is essential (Spano 2010).

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The demand for beverages and foods that promote good health has risen over the last few decades due to increasing health care expenses, longer life expectancy, and a desire for an improved quality of life (Menrad 2003). Foods that seem to be functional in this context ensure certain health benefits as a result of specific food components present in them. Different countries have various interpretations of what constitutes functional foods. Functionalized meals are meals with components that help influence certain bodily processes in addition to being nourishing. The concept of functional foods dates back to ancient China (as early as 1000 BC), where medicinal and healing qualities were attributed to certain foods and herbs. Food items enhanced with unique ingredients that have beneficial physiological effects were originally referred to as functional foods in Japan (Hardy 2000). Some of the prominent ingredients of functional foods and functions have bben exhibited in Table 13.1. The requirement for these was acknowledged since several demographic surveys showed that the cost of medical care for the aging population is high. As mentioned earlier, in 1984, the concept of functional food was introduced by Japanese researchers who investigated the relationship among nutrient intake, olfactory pleasure, fortification, and the manipulation of physiological systems. In 1991, FOSHU or Food for Specified Health Uses standards were established by the Ministry of Health (Burdock et al. 2006).

Table 13.1 Types of functional food ingredients and their mechanism of action

Functional food ingredients	Dietary sources	Function	Mechanism of action
Carotenoids	Carrot, other vegetables	Anti-inflammatory activities	Autophagy activation and promotion of apoptosis.
Fibre	Fruits, vegetables	Prevents breast, colon, ovarian cancer	Reduces the amount of time that carcinogens are in contact with the intestinal lumen while fostering a healthy gut flora.
Lycopene	Tomato, watermelon, pink grapefruit	Antioxidants	Reduces cellular DNA deterioration by scavenging free radicals.
Alpha-linolenic acid	Flax seeds	Antioxidant properties	Controls cell proliferation and lowers the risk of colon cancer.
Omega-3 fatty acid	Sea fishes like mackerel, tuna salmon, sardines	Antineoplastic	Proinflammatory lipid byproducts and growth factor receptor signalling are decreased
Multivitamins	Meat, fish, poultry, carrots, beans, sweet spinach, potatoes,	Reduces cancer incidence	Improving cellular metabolism and serve as essential cofactors and enzymes
Probiotics	Yogurt, curd, other milk products	Maintains healthy gut microbiota	Controls immunological reactions and intestinal epithelial homeostasis
Calcium	Milk products, almonds, eggs, chia seeds, soybeans tofu	Antineoplastic	Delay the onset of colon cancer and calcium sensing receptor (CASR)-mediated antineoplastic action

The Japanese obsession and research with functional foods have raised awareness of the demand for such goods in regions like Europe and the US. Researchers in these nations realized that functional foods might provide the food sector with a commercial opportunity to improve the quality of life and reduce healthcare expenses. However, the nature of functional meals differs greatly between Eastern and Western cultures. The function is more important than taste in the case of such goods, which are frequently referred to as first-generation functional foods. A functional food product is expected to have certain positive effects on one or more body functions and they are expected to lowering health issues. The USA is the most significant and active market for functional foods and this is anticipated to increase in the coming days (Bech-Larsen and Scholderer 2007).

The global market for these types of functional foods is expected to be atleast 33 billion US Dollars based on their health promoting factors and the value-added product (Hilliam 2000). It is expected that the US will become a major player in the FF market, accounting for 50% of the total global share. Currently other prominent nations in the FF market are the United Kingdom, France, Germany, and the Netherlands. Sales of FF have significantly increased throughout Europe with rapid expansion in Spain and the Netherlands (Jago 2009). According to Euromonitor, sales of FF in the emerging markets of Hungary, Poland, and Russia are expected to grow moderately from 2005 to 2009 (Benkouider 2004).

13.2 Examples of Functional Foods in Our Daily Life

Initially, functional food discoveries focused on fortifying foods with essential vitamins and minerals. However, this approach evolved over time to include meals enriched with various micronutrients such as phytosterol, omega-3 fatty acids, and soluble fiber, to foster good health or reduce risk of chronic diseases. Over the yars, these foods have become increasingly popular and gained significance in our daily healthcare. Consequently, certain developed foods can be classified into functional foods, with their role in maintaining healthy lifestyles falling into three categories i.e. (i) mitigating the risk of Chronic lifestyle diseases (ii) enhancing the cognitive functions of the individuals and (iii) reducing the existing health risk problems (Sloan 2002). Common types of functional foods have been listed in Table 13.2.

Almost all food industries have developed functional foods categories and the functional property is important from a product's perspective. They can be a different variety of foods, such as probiotics, prebiotics, functional drinks, functional cereals etc.

13.2.1 Probiotics

Probiotics refer live microorganisms that are benficial for the digestive system, immune functions, and overall health when consumed in adequate amount. They are bacteria or yeasts that are similar to those naturally found in the gut. The most

Table 13.2 Types of functional food with examples

Type of functional food	Definition	Example
Fortified product	A portion of food fortified with additional nutrients	Fortified milk, juices with vitamins
Enriched product	Food with added new nutrients and components usually not present in that food.	Margarine with plant sterol esters. Vitamin D enriched low fat milk.
Altered product	A food product from which unwanted harmful component is removed and added with more beneficial components.	Genetically modified food products.
Enhanced commodities	By using special growing conditions the specified needful components have been enhanced and thereby increased their therapeutic efficacy.	Cereals and pulses with higher vitamin and mineral levels.

common lactic acid bacteria (LAB) and bifidobacteria (Charalampopoulos et al. 2002). Probiotics are commonly found in feremented foods like yougurt, kefir, sauerkraut, kimchi as well as in various formulated dietary supplements. In the probiotics industry, microorganisms have been extensively investigated and implemented. These microorganisms are natural components of the gut microbiota and have a long-standing record of safe utilization in the food industry (Salminen 2007).

13.2.2 Prebiotics

Prebiotics are indigestible food components like fibers or carbohydrates that serve as a food source for beneficial microorganisms in the gut, such as probiotics and therefore, in turn, have positive effect on human health (Stanton et al. 2005). Prebiotics are typically found in plant-based foods, such as fruits, vegetables, whole grains, and legumes. The global prebiotic demand is estimated to be approximately 167,000 tonnes. Fructo-oligosaccharides (FOS), polydextrose, lactulose, isomalto-oligosaccharides (IMO), and inulin and resistant starch are the primary components of prebiotics. The use of oligosaccharides, has been shown to aid in the control of obesity by reducing hunger and, therefore, food intake (Bosscher et al. 2006). Non-digestible fermented fructans like oligofructose and inulin are among the most researched and established prebiotics (Gibson 2004). These substances have also been found to enhance calcium absorption, increase the bone mineral density, and bone mineral content (BMD) (López-Molina et al. 2005). Furthermore, they have been shown to reduce serum glucose and cholesterol levels. When probiotics and prebiotics are combined, they are referred to as symbionts due to their potential to work together effectively (Gibson and Roberfroid 1995).

13.2.3 Functional Drinks

Fruit juice has been suggested as a novel product category that is rich in essential vitamins, such as vitamins C, A, and E, and is regularly consumed by a considerble portion of the consumers (Tuorila and Cardello 2002). However, there is a vast array of products available within this category, and the European market dominates the sector. Other functional beverages are designed to decrease cholesterol levels by incorporating soy and omega-3 fatty acids and improve eye and bone health (Keller 2006).

13.2.4 Functional Cereals

Oat and barley are two types of cereal that provide another option to create foods with useful properties. The numerous advantages of these grains can be utilized in a variety of ways, such as the creation of unique cereal products or cereal ingredients. Cereals are also beneficial as a substrate for fermentation for the development of probiotic bacteria. In addition to fostering a number of advantages and physiological benefits, cereals encourage the growth of lactobacilli and bifidobacterial and act as prebiotics, and are found in the colon. Components of cereals like starch can be utilized as a material for probiotic encapsulation to enhance their stability while being stored and increase their vitality while passing through unfavorable GIT disturbances (Brennan and Cleary 2005).

13.2.5 Bakery Products

While the popularity of functional foods is rising quickly in recent decades such as confectionery or dairy products (Menrad 2003). By creating a new type of white bread, Unilever revolutionized the bakery industry referred to as Blue Band Goede Start, the original white bread containing nutrients typically present in brown bread such as inulin, fibers, iron, zinc, vitamins B1, B3, and B6 and that product was made up of wheat. In creating functional baked goods (Benkouider 2005), such as bread, it is crucial to recognize that establishing functional food quality delivery of the active substance at the proper dosage for physiological efficiency while also providing a product that fits the demands of the customer in terms of look and flavor also texture (Alldrick 2010).

13.2.6 Spreads

Spreads that reduce cholesterol are likely to become more popular recently because of their therapeutic functionality. For example, butter with low cholesterol under Balade ™, a trading name has been created and marketed since 1992, in Belgium.

Other milk with low cholesterol cheese, milk, and even low-cholesterol eggs are examples of these items. Furthermore, meat and its by-products can also be categorized as functional foods, to the extent that they include a wide range of substances considered to be functional. The notion of consuming food depends on health reasons. In addition to customary displays, the meat business can investigate a number of options, such as controlling the formulation of the makeup of the raw and processed material dietary fiber, antioxidants, or fatty acid profiles.

13.2.7 Eggs

Eggs are especially interesting due to their relatively high fatty acid content and the corresponding solubility in fat substances. Fatty acid composition is an important factor in determining one's health. Recently, antioxidants and other vitamins have been employed to create fresh foods or VITA Eggs. According to them, their eggs were supplemented with selenium, vitamins D, E, B12, omega-3 fatty acids, and vitamin B12.

13.3 Global Perspective on Functional Foods

The concept of functional food is a crucial development in the field of nutrition, as it encompasses all the fundamental scientific knowledge that has been accumulated over the last few decades. The progree must be acknowledged and utilized for the betterment of public health. A comprehensive overview of functional food concepts from around the world was presented at the Functional Food Science in Europe (FUFOSE) project (Roberfroid 2002). This project featured an overview of dietary choices, functional foods, and remedies for health and disease, as well as cultural and religious differences in Asia, Europe, Latin America, and North America.

13.3.1 Asian Dietary Ingredients

Having a thorough understanding of functional foods will empower food scientists to utilize them more effectively for promoting health. Asian functional foods gain populairty worldwide. In various Asian nations, the term "functional foods"encompasses a range of interpretations including nutritional supplements, foods enriched with minerals and vitamins, health foods, and Indian traditional medicine as well as the Chinese traditional medicine system (Zawistowski 2017). Functional foods have been an integral part of Asian culture for centuries, with a belief that food and medicine share the same origins and functions. Traditionally, many foods were used as medicine to treat various ailments (Asian Functional Foods 2005). Use of traditional insect foods as medicine by different ethnic communities in Arunachal Pradesh, therapeutic uses of edible snail by tribal population in Madhya Pradesh, use of food to treat diseases etc. are a few among examples of use of trational foods as medicines. The success of food manufacturers lies in creating products that align with customers' existing perception and values of functional foods. Functional meals are believed to have a significant impact on all aspects of health, from maintaining health to preventing disease (Arai 2002). In the Asian countries, particularly in metropolitan areas, Over the last two decades, there has been a significant shift in dietary patterns and the incidences of chronic diseases such as diabetes and heart diseas are on the rise due to adoption of Western-style diets and lifestyles.. As a response to market trends, the industry has increased its efforts to produce functional foods with specific health benefits (Zawistowski 2008).

13.3.2 European Dietary Ingredients

In contrast to Asia, the idea of functional foods is very new in Europe. The first country in Europe to implement laws and regulations concerning food claims was Sweden, with the "Code of Practice in the Labelling of Food with Health Claims" (Asp and Bryngelsson 2007). The primary legislation concerning food and food supplements in the EU is Regulation (EC) 1924/2006, which was last amended in 2014. This regulation applies to "food," as defined in Article 2 of Regulation 178/2002, last amended in 2018, and "food supplements," mainly vitamins and minerals, as described in Regulation 2002/46/EC, last amendment in 2017 (*Regulation (EC) No. 178/2002 of the European Parliament and of the Council Laying down the General Principles and Requirements of Food Law, Establishing the European Food Safety Authority and Laying down Procedures in Matters of Food Safety | UNEP Law and Environment Assistance Platform*, 2002). However, there is no specific regulatory framework or statutory definition for functional foods and nutraceuticals in Europe. The regulatory requirements for these products depend on their composition and substances they contain, which are subject to specific regulations in the Europen market. Therefore, functional foods and nutraceuticals that contain claims related to nutrition and health must comply with the guidelines established Regulation (EC) 1924/2006 (Domínguez Díaz et al. 2020). There are several frameworks implemented in the EU are respectively

I. **In the year 2002 –** Regulation (EC) No. 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety, concerned authority of European Food Safety Authority (EFSA) (*Regulation (EC) No. 178/2002 of the European Parliament and of the Council Laying down the General Principles and Requirements of Food Law, Establishing the European Food Safety*

Authority and Laying down Procedures in Matters of Food Safety | UNEP Law and Environment Assistance Platform, 2002)

II. **In the year 2002** – European Parliament and Council Directive 2002/46/EC of June 10, 2002, on Aligning the Laws of the Member States Relating to Food Supplements including bioactive products containing a higher quantity of vitamins and minerals (*EUR-Lex – 32002R0178 – EN – EUR-Lex*, 2002).

III. **In the year 2006 –** European Parliament and Council Regulation (EC) No. 1925/2006 of December 20, 2006, on the addition of vitamins, minerals, and certain other substances to foods (*EUR-Lex – 32006R1925 – EN – EUR-Lex*, 2006).

IV. **In the year 2013 –** European Parliament and Council Regulation (EC) No. 1925/2006 of December 20, 2006, on the addition of vitamins, minerals, and certain other substances to foods including taurine, inositol, amino acids, choline, carnitine, and nucleotides (*EUR-Lex – 32013R0609 – EN – EUR-Lex*, 2013).

V. **In the year of 2015 –** Legislation (EU) 2015/2283 of the European Parliament and the Council of November 25, 2015, on novel foods, amends Regulation (EU) No. 1169/2011 of the European Parliament and the Council, and repeals Regulation (EC) No 258/97 of the European Parliament and the Council, as well as Commission Regulation (EC) No. 1852/2001 excluding flavoring agents, enzymes, food additives (*EUR-Lex – 32015R2283 – EN – EUR-Lex*, 2015).

VI. **In the year 2017 –** According to Regulation (EU) 2015/2283 of the European Parliament and the Council on new foods, Commission Implementing Regulation (EU) 2017/2470 of 20 December 2017 establishes the Union list of novel foods (*EUR-Lex – 32017R2470 – EN – EUR-Lex*, 2017).

The European Commission's EU Framework Programs for the Research and Technology Development has been mentioned as the prioritized research on food and nutrition. Numerous EU initiatives from the 1990s focused on topics like fiber, probiotics, and prebiotics, but more current EU initiatives emphasize things like antioxidants, vitamins, and phytoestrogens as well as the socio-economic facets of diet and health.

13.3.3 American Dietary Ingredients

Food and drug standards in the United States are governed by the Food and Drug Administration (FDA) (Glasser et al. 2008). The regulatory framework in the US does not define functional foods and nutraceuticals. These goods are controlled as either foods or pharmaceuticals. The Dietary Supplements Health and Education Act (DSHEA) were passed by the US Congress in 1994. The DSHEA was created to control dietary supplement products. The US Food Drug and Cosmetic Act were modified by this act to include dietary supplements as a subcategory of food.

Therefore, items commonly regarded as functional foods and nutraceuticals are likely to be covered by American food legislation (*Office of Dietary Supplements – Dietary Supplement Health and Education Act of 1994*). The other exception, under which a product would not be regarded as a drug if it made a structure or function claim on the label or in labelling, applies to dietary supplement items. The Dietary Supplement Health and Education Act (DSHEA) of 1994 allows statements on supplement labels that describe the effects of a substance on the structure or function of the body, as long as they do not make any claim of curing or treating an illness (DSHEA which amended the FFDCA). However, if a product claims to diagnose, treat, mitigate, or prevent a condition, it would be classified as a drug (Young and Bass 1995).

13.3.4 Japanese Dietary Ingredients

Japanese people are recognized for their longevity and have a long history of eating foods that have health benefits. Foods for Specific Health Uses (FOSHU) are a functional food regulation that was adopted in Japan by the Ministry of Health, Labor, and Welfare in 1991. Following the development of the functional food system, several FOSHU products with positive health effects were created and released on the market. As a result, in 2007, FOSHU's net sales reached 6.2 billion dollars. The majority of health claims are related to probiotics to enhance digestive health. These claims are primarily associated with triglycerides, high blood pressure, high LDL-cholesterol, and high blood sugar (Iwatani and Yamamoto 2019) and are regulated by the Japanese Ministry of Health, Labour, and Welfare (MHLW) through "Foods for Specified Health Use" (FOSHU). Originally established in 1991, as we mentioned earlier, FOSHU's scope was expanded in 2001 to include capsule and tablet forms, and in 2003, around 330 items were recognized (Shimizu 2003). In April 2001, the MHLW implemented a new regulatory framework known as "Foods with Health Claims," which combined the FOSHU with "Foods with Nutrient Function Claims" (FNFC), covering twelve vitamins (A, B1, B2, B6, B12, C, E, and D) as well as two minerals (Ca and Fe) standardised under the FNFC (Warfel et al. 2007). These are some examples of statements made about these substances: "Calcium is a nutrient that is required to produce bones and teeth"; "Vitamin D is a nutrient that stimulates calcium absorption in the gut tract and aids in bone production." The maximum and minimum daily intakes of these nutrients are also established (Ohama et al. 2006). After 2007, the market for FOSHU goods was fully developed and generated $8 billion in sales in 2018 (Saito 2007; Iwatani and Yamamoto 2019).

13.4 Functional Food Marketing Development Considerations

Functional foods are becoming increasingly popular due to societal changes and trends in socio-demographics that them as a sustainable market for food (Bech-Larsen and Scholderer 2007). This is supported by the growing awareness among professionals and consumers of the tight relationship between diet and health status (Young 2000). A number of studies show that customers are also more thoughtful about health issues and willing to embrace dietary adjustments that are focused on health (Niva 2007). The benefits of functional food products cannot be overlooked to maintain general health to treat particular medical situations with a practical approach (Poulsen 1999). Furthermore, it goes beyond the economic and societal considerations (Jones and Jew 2007). This growing consumer consciousness together with improvements in numerous scientific fields provides businesses opportunity to create unlimited variety of new healthy food concepts (Biström and Nordström 2002).

While the benefits mentioned earlier are clear, the production and trade of these products can be complicated, and more expensive (Van Kleef et al. 2002). To successfully develop and market these products, significant research efforts are required to identify useful molecules, evaluate their physiological effects, creating an appropriate food matrix, and consider potential changes in bioavailability during food preparation and processing. Additionally, consumer education, and clinical trials to establish efficacy of the product and gain permission for marketing claims promoying health are necessary (Kotilainen et al. 2006). Table 13.3 represents the clinical studies of different functional foods. This process involves multiple stages and requires collaboration among business, academia, and regulatory bodies, with a focus on winning consumer trust and acceptance (Jones and Jew 2007). To ensure the successful development of functional foods, it is crucial to consider both consumer preferences and market opportunities from the outset, as well to take into account legislative rewuirements (Menrad 2003). Consumers' top health concerns include cardiovascular diseases, hypertension, stress, cancer, obesity, arthritis, and gastrointestinal conditions, according to research studies (Drbohlav et al. 2007). From the viewpoint of the consumer, the achievement of functional foods is dependent on several interrelated factors, such as considering the level of overall health concern and various medical conditions, and the idea that one's health may affect another's personal well-being. Qualitative studies has shown that consumers often lack the necessary background information to assess specific functional claims of a food products (Bech-Larsen and Scholderer 2007).

Table 13.3 Clinical trial with functional foods

SL No	Functional food	Disease	Population	Study design	Results	Reference
1.	Synthetic genistein	Prostate cancer	54 patients	For 3–6 weeks synthetic genistein (30 mg) daily	Decreases serum prostate specific antigen (PSA)	
2	Flaxseed	Prostate cancer	147 patients	Flaxseed (30 mg) 30 days	Important inverse association between enterolactone and total urinary enterolignans and Ki67 in the tumor tissue	
3	Curcumin and quercetin	Adenomatous polyposis	5 familial adenomatous polyposis	Quercetin (20 mg) and curcumin (480 mg) thrice daily for 6 months	Polyp number and size reduced from baseline without appreciable toxicity	
4	Curcumin	Colorectal cancer	126 patients	Curcumin (360 mg) thrice daily for 10–30 days	Increased expression of p53and body weight, serum level of TNF-α suppressed	
5	Fruit and vegetables	Colorectal cancer, colon cancer, and rectal cancers	61,463 women were recruited, 460 colorectal cancer 291 colon cancers, 159 rectal cancers, and 10 cancers at both sites)	Individuals who consumed less than 1.5 servings of fruit and vegetables per day	Relative risk for developing colorectal cancer of 1.65 (95% confidence interval¼1.23 to 2.20; Ptrend¼0.001)	
6		Metastatic melanoma Stage IV	112 patients with metastatic melanoma were recruited at MD Anderson cancer	Before and after treatment with PD-1 inhibitors were progression-free	Survival was significantly longer for patients with a high diversity in their gut	
7	Beta-carotene, alpha-tocopherol, selenium	Esophageal and gastric cancer	General population nutrition intervention trial, China healthy men and women at increased risk of developing cancer	30 mg alpha-tocopherol, 15milligrams (mg) beta-carotene and 50 micrograms (μg) selenium daily for 5 years in Linxian	Initial: No effect on risk of developing either cancer; decreased risk of dying from gastric cancer only later	

(continued)

Table 13.3 (continued)

SL No	Functional food	Disease	Population	Study design	Results	Reference
8	Pomegranate juice	Hypertension	Randomized hypertensive patients 10	Pomegranate juice consumption (50 mL, 1.5 mmol of total polyphenols per day, for 2 wk)	Reduction in serum ACE activity decrease SBP	Aviram and Dornfeld (2001)
9	Orange juice	Hypertension	Randomized, placebo-controlled 22 healthy volunteers	500 mL commercial and fresh orange juice, 4 weeks consumption of both juices	Decreased VCAM, hs-CRP, and selectin but increased Apo A-1. SBP and DBP were significantly decreased	Asgary and Keshvari (2013)
10	Omega-3 fatty acid	Cholesterol, blood sugar	Randomized, double-blind, placebo-controlled trial	48 coronary artery disease Omega-3 fatty acid supplement (720 mg eicosapentaenoic acid plus 480 mg docosahexaenoic acid) for 8 weeks	Increased serum irisin, decreased serum hs-CRP and LDL-C, not result in any significant changes in anthropometric measurements, blood pressure, serum lipids except for serum LDL, fasting blood glucose, body composition, or serum insulin level	Agh et al. (2017)
11	Garlic	Antiplatelet aggregation	Randomized, double-blind, crossover	Garlic 34 normal healthy adults' AGE/placebo, AGE: 2.4–7.2 g/day t.i.d., 44 weeks	Antiplatelet aggregation and adhesion	Steiner and Li (2001)
12	Garlic	CAC progression	Randomized	Garlic 65 asymptomatic patients with CAC >30%	AGE C vitamin B12 C folic acid C vitamin B6 C L-arginine/placebo, AGE: 250 mg, 1 year CAC progression: 65% reduction	Babu et al. (2013)
13	Nigella sativa oil	Cardiometabolic risk factors	Randomized controlled clinical trial 90 obese women	Nigella sativa oil 3 g per day for 8 weeks	Decline triglycerides and VLDL. NS oil concurrent with a low-calorie diet can reduce in obese women	Mahdavi et al. (2015)

14	Nuts	Cardiovascular risk factors	Randomized crossover	Nuts 72 participants 30 g/day of either raw or dry roasted, lightly salted hazelnuts for 28 days	Decreases LDL, TG; consuming both forms of hazelnuts significantly improved HDL-C and Apo A1, TC/HDL-C ratio, and SBP by consumption of dry form	Tey et al. (2017)
15	Legumes	CVR	Randomized controlled crossover trial	64 middle-aged men who had undergone colonoscopies-C/HDL-C	Legume enriched (1.5 servings/1000 kcal) for 4 weeks decreases TC, LDL, TC/HDL-C, and LDL	Zhang et al. (2010)
16	Coffee and tea	Atrial fibrillation and CVD	Cohort study	33,638 healthy women free of cardiovascular disease and atrial fibrillation at baseline	Elevated caffeine consumption was not associated with an increased risk of incident AF caffeine intakes across increasing quintiles of caffeine intake were 22, 135, 285, 402, and 656 mg/day	Conen et al. (2010)
17	Resveratrol	CVR	Randomized, placebo-controlled trial in postmenopausal women	Consumption of 150 mg of *trans*-resveratrol for 14 weeks	17% elevation in cerebrovascular responsiveness (CVR) and verbal memory as well as mood (cognition)	Evans et al. (2017)
18	Green tea catechin	Functional disability	Cohort study	13,988 Japanese individuals aged ≥65 y	3-y incidence of functional disability was 9.4% (1316 cases)	Tomata et al. (2012)
19	Dietary n-3 polyunsaturated fatty acids	Alzheimer disease	Prospective study	A total of 815 residents, aged 65–94 years, who were initially unaffected by Alzheimer disease	Participants who consumed fish once per week or more had 60% less risk of Alzheimer disease	Cardiology, JAMA Neurology, JAMA Network (2022)
20	Curcumin	Depression	A randomised, double-blind, placebo-controlled study	56 individuals with major depressive disorder were treated with curcumin (500 mg twice daily) or placebo for 8 weeks	Improving several mood-related symptoms, demonstrated by a significant group x time interaction	Lopresti et al. (2014)

13.5 Sources of Phytoconstituents with Therapeutic Activity

Plants contain a vast array of bioactive compounds (Fig. 13.1). They are secondary metabolites, essential for plants to protect them from pest and ensure plant health, are having significant functional properties when consumed as food (Oboh and Akindahunsi 2004). A low incidence of certain chronic diseases is connected with dietary intake of natural bioactive substances (Lima et al. 2014). According to epidemiological, clinical, and biochemical, these bioactive compounds have different activities in the body through different mechanisms, including antioxidant, antidiabetic, antihypertensive, and anti-Alchemic activities (Gupta and Prakash 2019). Antioxidants are essential in maintaining good health and preventing various diseases (Gupta and Prakash 2019). Free radicals, unstable molecules produced by metabolic processes, exposure to pollution, stress, and other factors, causesdamage to cells and tissues and antioxidants work by neutralizing free radicals and protecting the body from their hamful effects (Alía et al. 2003; Rakesh et al. 2010). Consuming a diet rich in antioxidants, which can be found in vegetables, fruits, nuts, whole grains, seeds, and, seasonings made from herbs, can help rejuvenate the body, delay the onset of age-related processes, and prevents degenerative illnesses (Adefegha et al. 2017). Additionally, functional foods, dietary supplements, and nutraceuticals in one's diet can provide antioxidant benefits and serve dietary remedies for a variety of illnesses (Olaiya et al. 2016). Flavonoids and phenols protect body cells from damage caused by oxygen, which is peoduced during energy production and can cause oxidative stress (Stratil et al. 2008). Natural polyphenols, mainly derived from plant sources, can neutralize free radicals, and activate antioxidant enzymes (Rakesh et al. 2010).

Phenolic Acids Phenolic acids are widely distributed in plants (Saxena et al. 2012) and are characterized by their hydroxycinnamic and hydroxybenzoic acid structures. The functions of these compounds in plants are still being studied. However,

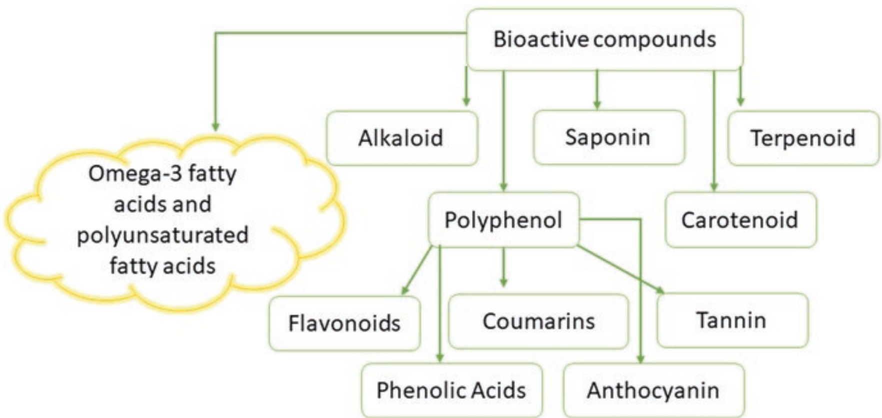

Fig. 13.1 Functional food bioactive components present in plants

phenolic acids have been found to play significant roles in enhancing the taste, appearance, nutritional and antioxidant properties of foods (El Gharras 2009). Gallic acid, caffeic acid, chlorogenic acid, p-coumaric acid, ferulic acid, vanillic acid, and protocatechuic acid are the most common types of phenolic acids (Robbins 2003). The concentrations of these compounds can be affected by environmental factors like temperature (Yousfi et al. 2006). The metabolic functions and bioavailability of these substances are nor fully understood, but the research has been conducted on the activity of ferulic, caffeic, and chlorogenic acids as they are involved in the management of certain disorders such as asthma, and allergic reactions (Yasuko et al. 1984).

Flavonoids Flavonoids are a major group of phenolic compounds that can be found in various plant-based diets. These secondary metabolites are synthesized through the phenylpropanoid pathway in plants (Liu 2002). Up to 6000 flavonoids have reportedly been discovered and isolated, with a majority being found in plants (Tolonen et al. 2002). Flavonoids can be classified into six main classes based on structure of their heterocyclic ring C (Temidayo 2013), which are flavonols (Eg: quercetin, myricetin, kaempferol, and galangin), flavones (Liu 2002) (apigenin, luteolin, and chrysin), flavanols (catechin, epigallocatechin, epicatechin, epicatechin gallate), anthocyanidins (peonidin, cyanidin, pelargonidin, malvidin, and delphinidin), isoflavonoids (daidzein, glycitein, genistein, and formononetin), and flavanones (naringenin, hesperetin, and erifoods. The primary flavonoids, such as quercetin, epicatechin, and cyanidin are found in apples, tomatoes, pineapples, guavas, and avocados contain a substantial quantity of rutin and quercetin. The free radical scavenging activity of flavonoids for preventing the generation of protein oxidation and lipid peroxidation products has been linked to their antioxidant capabilities (Kahali et al. 2014).

Alkaloids Alkaloids are secondary metabolites found in plants, fungi and animals and possess biological activity (Demirgan et al. 2016). These substances are composed of basic nitrogen with heterocyclic rings. These compounds are synthesized through the transamination reaction steps or the pathway for the biosynthesis of amino acids in plants. Alkaloids come from diverse range of botanical sources, and have various chemical compositions (Aniszewski 2007). Many of them exhibit pharmacological properties and are potential candidates for drug discovery.

Carotenoids Carotenoids are family of naturally occurring pigments that are lipid-soluble present in both animals and plants (Mortensen 2006). They are categorized based on specific traits and are considered part of the class of bioactive chemicals called isoprenoid polyenes. Due to their complicated structure, which includes several conjugated double bonds and cyclic end groups, carotenoids are among the most complex bioactive molecules. Over 700 carotenoids have been identified, however, only 50 are efficiently metabolized and digested (Grune et al. 2010). Some of the metabolizable carotenoids are lycopene beta-carotene, alpha-carotene, and xanthin those are frequently found in the blood. Epidemiological studies indicate that consuming large amounts of carotenoids provide numerous health benefits, as their antioxidant properties contribute to overall health (Miller et al. 1996).

13.6 Role of Functional Foods and Bioactive Compounds in Chronic Degenerative Diseases

The primary causes of morbidity and mortality worldwide are chronic lifestyle diseases, including cancer, cardiovascular diseases, arthritis, obesity, diabetes, and respiratory and neurological disorders. The influence of degenerative illnesses on quality of life, health, and life expectancy is enormous. These illnesses are spreading quickly over the world and are responsible for roughly half of the global burden of diseases and most of the documented global fatalities. Cardiovascular illnesses account for around half of all chronic disease-related deaths, and obesity and diabetes, which are now common in childhood, also play a significant role (Francesco et al. 2013). In many countries around the world, cancer and cardiovascular disease (CVD) are the two main causes of death. According to epidemiological and experimental research, consuming a lot of fruits, fish, spices, beverages, legumes, vegetables, whole grains, and other food-related products is strongly associated with a lower risk of developing chronic diseases (Hooper and Cassidy 2006).

13.6.1 Diabetes Mellitus

Diabetes mellitus is a chronic metabolic disorder caused by inadequate or ineffective insulin secretion and changes to the metabolism of carbohydrate, protein, and lipid. The most prevalent form of this chronic condition is type 2 diabetes mellitus, which is not insulin-dependent (American Diabetes Association 2009). Extracellular hyperglycemia can induce tissue damage and diabetic consequences include heart disease, neurological illnesses, and diabetic retinopathy, etc. (Brownlee and Cerami 1981). Enzymes hydrolyze carbohydrates into glucose, which is then taken up by the intestinal epithelium and released into the blood circulation. Plant phenolics can inhibit these enzymes, delaying glucose absorption and reducing postprandial hyperglycemia. Studies have found that the phenol concentration and components of plant foods are responsible for their enzyme inhibitory actions (Nong and Hsu 2021). The antioxidant activity of phenolics may influence the five disulfide bridges on the outside of amylase, which could lead to inhibition via modulating changes in the enzyme's structure (Adefegha 2018). Flavonoids with more hydroxyl groups have stronger inhibitory effects on α-amylase activity, and green tea contains catechins and their derivatives, which may have anti-diabetic properties (Rasouli et al. 2017). Some flavonoids and flavones inhibit pancreatic α-amylase and it's interesting to note that intestine-glucosidase and pancreatic α-amylase activity can both be inhibited by cyanidin and its glycosides. In vitro and in vivo studies have demonstrated that phenolic acids with significant α -glucosidase inhibitory activity include gallic, caffeic, rosmarinic and chlorogenic acids (Ali et al. 2020). A significant α-glucosidase activity was also present in the sacrcoviolins and sarcoidosis that were isolated from the edible fungus Sarcodon leucopus (K. Ma et al. 2014). The presence of many hydroxyl groups on the structure was thought to be the cause of their inhibitory actions. It has been demonstrated that these hydroxyl groups play an important role in the inhibition of the enzyme (Ma et al. 2010).

Scientific evidence suggests certain alkaloids can act as enzyme inhibitors. Vasicinol and vasicine, for instance, have been found to exhibit high sucrase activity. Furthermore, the amount of caffeoyl groups in the structure of 3,4, 3,5, and 4,5-diccaffeoylquinicids can inhibit the maltase enzyme. Another example is berberine from *Tinospora cordifolia*, which has been shown to inhibit disaccharides and delay glucose absorption across the intestinal epithelium in Caco-2 cells (Singh et al. 2016). Similarly, 4-hydroxy isoleucine has been found to have hypoglycemic properties in alloxan-induced diabetic mice. These compounds were extracted from *Trigonella foenum graecum* seeds, having glucose-lowering impact when used in hyperglycemic conditions. In addition, 4-hydroxyisoleucine oral delivery to alloxan-induced diabetic rats resulted in beta cell regeneration as opposed to control animals that had damaged cells. The antihyperglycemic effect of β-carboline alkaloids has been demonstrated in prior research on natural antidiabetic drugs (Osigwe et al. 2015). Triterpenoids are well established to be effective hypoglycemic medications. Triterpenoids and their glycosides have been shown to have anti-diabetic properties in numerous investigations. Momordica charantia contains a steroidal saponin called charantin, which causes the release of insulin and prevents the bloodstream from absorbing glucose, causing it to have anti-diabetic properties. Aldose reductase hampering is yet another useful therapeutic strategy for the treatment of diabetes (Tang et al. 2012). By using the polyol pathway, aldoreductase catalyzes the conversion of glucose to sorbitol. High amounts of glucose may be influenced by hyperglycemia to enter the polyol pathway, which would result in an accumulation of sorbitol. Aldose reductase has been demonstrated to be effectively inhibited by a few natural bioactive substances.

Over time, there has been an increasing interest among researcher in exploring flavonoids and their derivatives as inhibitors of aldose reductase. Recent studies have suggested that hydroxylation, glycosylation, and hydrogenation of the double bond in flavonoids contribute to their inhibitory effect on aldose reductase activity. Polyphenolic components in green tea leaves have also been identified as potent aldose reductase inhibitors, with galloylated catechins exhibiting stronger inhibitory effects compared to nongalloylated catechins. The catechins' glycosylation was thought to be responsible for the stronger inhibitory effects (Plumb et al. 1998). Hispidin, inotilone, and hispolon are phenolic substances that were that were identified from an ethanol extract of Phellinus merrillii and found to be strong inhibitors of aldose reductase (Huang et al. 2011). Caffeic acid, gallic acid, caffeoylquinic acid, and p-coumaric acids, which have all been found in coffee beans, have been reported to be powerful inhibitors of aldose reductase (Xiao et al. 2015). These bioactive compounds' ability to inhibit aldose reductase has been associated with hydrogenation of the double bond and glycosylation of the stilbene structure's position.

13.6.2 Cardiovascular Diseases

Multiple elements make up the complicated and multifaceted condition known as cardiovascular disease (CVD). According to epidemiological research, the prevalence of CVD is rising. It is distinguished by various risk factors, including high blood pressure, poor diets, age, ethnicity, and family history increased serum lipids, obesity, type 2 diabetes, high blood pressure (cholesterol and triglycerides), enhanced platelet activation, elevated plasma fibrinogen and coagulation factors, and changes in oxidative stress, smoking, and glucose metabolism (WHO 2002).

Hypertension affects a significant pertange of people in several European countries, ranging from 30% to 45%, with its occurrence increasing gradually with age. The renin-angiotension system (RAS) is another critical enzyme that impacts blood pressure regulation, salt and water balance, as well as the development of cardiovascular and renal diseases (Maimaiti et al. 2019) (Fig. 13.2). RAAS dysregulation significantly influences the pathogenesis of these diseases. When stimulated, angiotensinogen release angiotensin I, which is then converted into angiotensin II by ACE, a potent vasoconstrictor. ACE inhibitors (ACEIs) reduce both local and

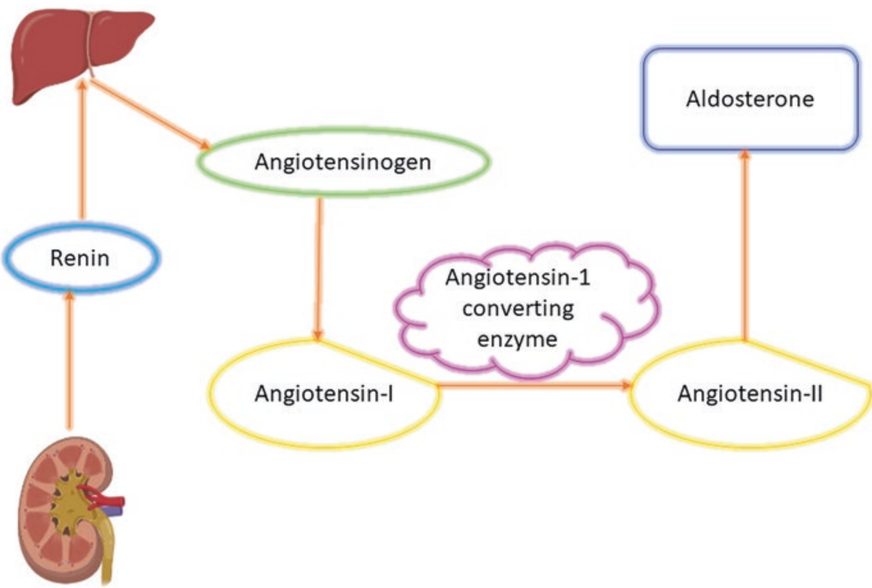

Fig. 13.2 Renin-Angiotensin mechanism

systemic levels of Angiotensin II (Ang II). Although the effectiveness of ACEIs in suppressing additional "tissue" functions of the RAAS is debatable, they also reduce sympathetic nerve activity and secretion of aldosterone and vasopressin secretion (Di Raimondo et al. 2012).

The prevention and treatment of hypertension and heart-related disorders are made easier by the use of functional foods and food items including cocoa, coffee, and condiments. The bioactive components of these functional meals are responsible for the therapeutic effects they produce. Recent studies have demonstrated the beneficial effects of these bioactive compounds by regulating abnormal lipids, lipoproteins, blood pressure, inhibiting platelet aggregation, and boosting antioxidant status.

13.6.3 Neurological Disorders

Dementia is a condition that occurs as a result from neurodegenerative illnesses, which involve gradual deterioration of neuronal integrity in the brain and spinal cord. The increase in neurodegeneration worldwide has been linked to the aging process which is often accelerated by excessive reactive oxygen species (ROS) production (Rohowetz et al. 2018). As oxidative stress accumulates, it can lead to mitochondrial dysfunction and oxidative damage, which in turn may result in neurodegenerative illnesses those are characterized by memory loss and cognitive dysfunction (Islam 2017). The brain is a crucial organ in the body that regulates both physiological and mental processes through the complex communication networks between its billions of neurons (Pushpalatha et al. 2013). To maintain optimal function, it is essential to manage oxidative stress and regulate neurotransmitters.

Cholinesterase inhibitors are the primary medications frequently prescribed for treating Alzheimer's disease (Haake et al. 2020). There has been a recent focus on tropical plant-based diets that are rich in antioxidants and phytochemicals to promote health as potential therapeutics. Epidemiological studies have shown that consuming fruits, vegetables, drinks, and spices, medicinal herbs may reduce the risk of developing neurodegenerative illnesses. The neurotransmitter acetylcholine (ACh) is hydrolyzed by the enzyme acetylcholinesterase (AChE), which is bound to the membrane. Low levels of ACh can be caused by hypoinsulinemia (low blood insulin levels) and insulin resistance, which may indicate a potential biochemical relationship between diabetes mellitus and Alzheimer's disease (Boccardi et al. 2019). Oxidative assaults can also affect Ach and contribute to the development of various diseases, such Alzheimer's disease, CVD, and diabetes mellitus (Mushtaq et al. 2015). The research on protocatechuic acid's potential effects showed that it changed the activity of the enzymes Na+/K + -ATPase, cholinergic, and antioxidant in rats (Adefegha et al. 2016). It has also been noted that in an in vitro model, alkaloid extracts from breadfruits and shea butter were able to prevent lipid peroxidation, monoamine oxidase, and cholinesterase (Adefegha et al. 2017).

13.6.4 Cancer

Epidemiological research conducted over the past three decades has found a direct link between the consumption of bioactive substances present in food and a lower the risk of cancer (Ruiz and Hernández 2014). Studies have shown that beta-carotene, lycopene, beta-cryptoxanthin, fibre and omega-3 fatty acids, when included in the diet, are useful in the managing cancer (Aghajanpour et al. 2017). Proteins present in unprocessed extracts and even whole meals are also believed to possess anti-tumor properties (Idowu et al. 2021). Functional foods contain bioactive substances that can have the potential to act as antimetastasis agents, reverse drug resistance in cancer cells and improve the sensitivity of cancer cells to treatment. To better understand how functional foods affect cancer, numerous significant randomized clinical trials currently underway (Russo et al. 2017).

Polyohenols present in food have been found to affect epigenetic changes through the expression of microRNAs associate with the fate of cancer cells and posttranslational modifications (Lall et al. 2015). Clinical investigations on polyphenolic phytochemicals have used tea polyphenols to treat and prevent cancer, while data ob cucurmin and soy isoflavones have shown mixed rsults (Yang et al. 2021). Dietary polyphenols can affect prostate cancer cells by controlling inflammatory genes and repairing oxidative DNA damage. Additionally, interactions between various dietary polyphenols may alter the risk of prostate cancer by activating both antioxidant and non-antioxidant pathways (Lall et al. 2015). Green tea's polyphenol content, including catechin, is primarily responsible for the beverage's health-promoting properties (Kazimierczak et al. 2015). Tea polyphenols were discovered to inhibit tumorigenesis in animal research in a number of organs, including the skin, oral cavity, lung, esophagus, stomach, colon, liver, small intestine, pancreas, and mammary gland (AL et al. 2020). Curcumin, a polyphenol produced from turmeric, has a variety of anti-inflammatory and anticarcinogenic properties. Research suggests that it can prevent tumor invasion and metastasis by modulating a number of signaling pathways in cells. Through the reduction of angiogenesis and metastasis, interference with cell cycle progression and apoptosis, and other mechanisms, curcumin may control the growth, development, and dissemination of cancer (KM et al. 2021). According to recent research, curcumin may improve the efficacy of chemotherapy and shield healthy cells from radiation damage (Hatcher et al. 2008).

One of the most prevalent acyclic carotenoids is lycopene, which can be found in watermelons, pink grapefruits, tomatoes, and tomato-based goods. Lycopene functions as a potent antioxidant that reduces the damage of DNA by disarming free radicals produced by both internal cellular processes and external factors like pollution and UV radiation (Bacanli et al. 2017). Additionally, it affects phase II detoxifying enzymes, antioxidant changes, growth factor signaling control, cell cycle arrest, anti-inflammatory conditions, and apoptosis (Holzapfel et al. 2013). Strong antioxidant and antiangiogenic properties are shown by the isoflavone and phytoestrogen genistein. Numerous studies have shown that genistein inhibits topoisomerase II, which causes fragmentation of DNA and cell death and which leads to cell differentiation. The levels of tumor biomarkers in several cancer cell lines can be reduced by genistein (Sarkar and Li 2003). Future research is required to determine the efficient therapeutic dose of genistein for the treatment of particular cancer types (e.g., microRNAs).

In addition to vitamins and minerals, mushrooms also provide high concentrations of uncommon antioxidants such as ergothioneine (Podkowa et al. 2021). By interacting with the gut microbiota, mushrooms and mushroom extracts strengthen the immune system and control inflammations, enhancing adaptive immunity and immune cell activity (Feeney et al. 2014). In Asia, more than 100 different varieties of mushrooms are utilized to treat cancer. In particular, numerous medicinal mushrooms appear to share specific polysaccharide-mediated anticancer immunomodulatory effects (Blagodatski et al. 2018). In Japan, a mushroom product called PSK is authorized for use in the treatment of patients with lung, colorectal, breast, and stomach cancer (PDQ Integrative 2019). According to preclinical and clinical research, mushrooms have complex anticancer properties that may manifest not only through the inhibition of specific cancer mechanisms but also through indirect processes including immunomodulation. Consuming grains, beans, and bean fiber has been found to reduce the risk of breast cancer (Vetvicka et al. 2021). Fiber can shorten the time that carcinogens come into contact with the intestine and support healthy microbiota, leading to changes in how the host's immune system is metabolically regulated, and this can prevent the growth of cancer cells and inducing apoptosis (Zeng et al. 2020). Flaxseed, which is high in lignin, fiber, and other phytochemicals, has been linked to decreased angiogenesis and cell proliferation, as well as increased apoptosis (De Silva and Alcorn 2019). Flaxseed is effective at halting the development of colon cancers in both human and animal models (Ganorkar and Jain 2013). Nuts are rich in fibre, vitamins, unsaturated fatty acids, carotenes, and phenolic compounds and their inclusion in the diet has been shown to reduce the risk of colorectal, stomach, esophageal, pancreatic, anal, and endometrial cancers (Rock et al. 2020).

Appropriate food and bacteria in the body can prevent the spread of cancer, increase the effectiveness of chemotherapy, and reduce the side effects caused by chemotherapeutic synthetic drugs. Certain probiotics can also trigger anticancer pathways by modulating gut epithelial homeostasis and immune responses. For example, *Lactobacillus acidophilus* and *Lactobacillus casei* have been shown to improve the ability of 5-fluorouracil to induce apoptosis in the colorectal cancer cell line LS513 and milk that has been fermented with probiotics may help prevent stomach cancer (Marinelli et al. 2017). *Lactobacillus reuteri* decreases the proteins that promote cell proliferation or block apoptosis and triggers TNF-induced apoptosis through the modulation of NF-B and MAPK signalling (Plaza-Diaz et al. 2012).

13.7 Future Prospect and Conclusion

More research in this area of functional foods is need of the hour. But clinical studies revealed that it is not predictable in global perspective. Few steps like regulations and implementation should be strictly followed while marketing a functional food. Functional food should be region specific as it will be more helpful in fulfilling its role and demand.

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Chapter 14
Medicinal Properties of Traditional Foods and Associated Indigenous Knowledge System: A Case Study of the Himalayan Region, India

Khemkaran Ahirwar and Junaid Khan

14.1 Introduction

Indigenous foods (IFs) have a unique cultural significance in India, like other parts of the world, yet there have been limited efforts to compile their nutritional contents. FAO's call for a "Global-Hub on Indigenous Food Systems," has broadened the scope of addressing the role of IFs to advance food security while aiding in the conservation of biological diversity. The benefits of IFs need to be explored and documented adequately to bridge indigenous and science-based knowledge systems.

Traditional food systems are characterized by lack of processing, small volume, less involvement of technology, and short farm-to-plate value chains. Surrounding ecosystem, geographical and environmental condition, socio-cultural norm, and historical experiences all contribute to the formation of a dietary habit and therefore food system of an ethnic group and often include harvesting, foraging, hunting, fishing, and gathering plant and animal feeds. Living in a proximity with nature and complete dependence on it help indigenous people to develop a dynamic body of knowledge associated with utilization of surrounding natural resources for food as well as medicinal purposes. Indigenous food systems have allowed them to thrive for millennia by providing nourishment (Fig. 14.1) without negatively impacting the natural environment.

Looking at India, there are 705 indigenous villages in India and each has different food systems that feature a unique selection of indigenous foods (IFs) (Misra et al. 2008). To survive, indigenous communities rely on the wealth of natural resources found in the forests, hills, rivers, etc. that surround their homes (MoHF and Ministry of Tribal Affairs 2019). Their IFs also include greens (leaves, stems, shoots, including marine algae), root vegetables (including true roots and

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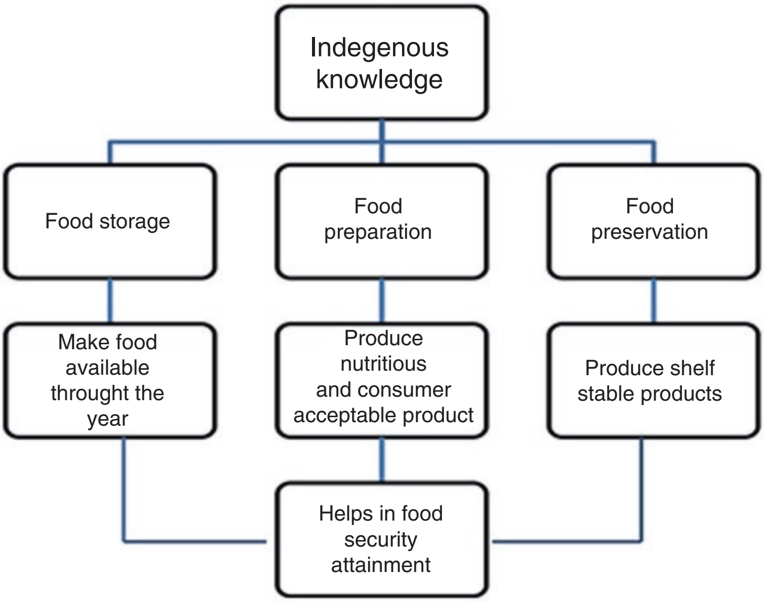

Fig. 14.1 Schematic diagram showing the role of Indigenous knowledge of food to achieve food and nutrition security

underground storage organs like bulbs, corms, tubers, and rhizomes), fleshy fruits (berries, pomes, drupes), grains, seeds, nuts, edible wild mushrooms, games, insects and other edible invertebrates (Chakravorty et al. 2013; Baghele et al. 2021). Similarly, people living in arid areas, as an example of Native Americans, developed knowledge of utilizing diversity of desert-adapted plants including a wide range of edible herbs, bushes, cactus, and trees for their nourishment. Many indigenous tribes have customized these IFs to their unique climatic and environmental situations.

Despite having access to a wide range of foods, indigenous people in India are critically malnourished due to the poor quality of meals (Kapoor et al. 2022). Urbanization, migration, the ongoing dietary transition etc. are leading to the loss of indigenous communities' agricultural and natural resource management practices, and erosion of traditional ecological knowledge (TEK), which possibly explain the declination of IF consumption and deteriorating the nutritional status of the population. Therefore, it is crucial to document TEK, explore the nutritional potential of community-specific IFs, and promote their consumption as a strategy to combat malnutrition and hunger not only among indigenous communities but also other population of the country. Although several investigations have uncovered and cataloged the IFs eaten by India's native populations, comprehensive effort is yet to be taken to explore their nutrient profiles. Besides, to bridge the gap between the science-based knowledge and the ancient indigenous wisdom, validation of curative properties of wild IFs is also required.

Food is now seen as carrying essential information for people's health, nutrition, culture, and tradition, which has led to a rise in interest in food literacy in modern society (Thompson et al. 2021). Literacy in the realm of food, then, encompasses not only the knowledge of where and what foods are grown but also their cultivation and production, as well as their processing and consumption (how food is prepared and distributed). Each of these areas of expertise can be picked up informally through people's everyday experiences in their homes and communities or officially through the kind of curriculum-based learning that is commonplace in educational institutions (Rosas et al. 2019).

As the world's population continues to rise, so does the urgency that we must discover long-term solutions for feeding everyone without having negative impact on environment (Chu and Karr 2017). An ecosystem approach to agricultural management that places value on time-tested practices already in use by local communities could be one solution. Food security, nutrition, and health could all be improved by tapping into the Indian tribal environment's bountiful supply of naturally occurring crops. A country in economic transition like India is facing the additional difficulty of a rapidly altering landscape, threatening both human livelihoods and agricultural and natural biodiversity. In this chapter we explored the traditional foods of plant origin utilized by the Bhotiyas of central Himalayan region of India as sources of nutrition as well as medicinal purposes.

14.2 Bhotiyas in the Central Himalayan Region of India: Study Area

The Bhotiyas inhabit the furthest northernmost reaches of the Central Himalayas three communities belonging to Bhotiyas namely Tolchha, Marchha, and Jadhs were studied to explore and document their traditional knowledge associated with utilizing plants for food as well as medicinal purposes. Districts of Chamoli, Uttarkashi, and Pithoragarh in Garhwal make up this area of Bhotiya habitat. Because of the search for grazing areas for their sheep, these communities engage in migratory agriculture. They spend the summer in their traditional homes in the mountains (at an altitude of 2000–3600 meters above sea level) where the weather is quite harsh and spend the winter in the warmer valleys (400–1400 masl). The Jadhs live around 300 km away from the other two groups in the Bhagirathi valley in the Central Himalayas. Two of the communities, Tolchha and Marchha rely primarily on agriculture, while Jadh relies more on pastoralism. They all depend entirely on the plants of the surrounding ecosystems for their survival. From the point of view of belief system, Jadhs are Buddhist, Tolchhas are Hindu, and Islam is dominating among Marchhas.

Traditional agriculture and animal husbandry in these villages are intertwined with the forest ecosystems, much like elsewhere in the Central Himalayas. Besides cereals and coarse grains, they specialize in growing cash crops, including kidney beans, buckwheat, amaranth, and potato. Livestocks mainly include sheep, goats, cattle, bullocks, horses, and mules. Sheeps serve as the poor man's cash crop and goats as their subsistence animal in these regions.

Many Bhotiya households, like other traditional and tribal cultures in India, rely heavily on plant and animal resources that originate in the wild to ensure their survival. During the famine, when grains like rice, buckwheat, and barley are few, people typically eat edible wild fruits, seeds, and leaves. Personal household incomes are also benefitted from the sale of wild resources. Some families supplement their food budgets by selling unused household items. In some places, selling items made from native plants is the primary source of income.

14.3 Traditional Foods and Medicines of Plant Origin Used by Bhotiyas

Table 14.1 represents several wild plant species those are harvested in considerable quantities for usage in the Himalayan village ecology. Table 14.2 is a comprehensive list and description of the uses of the plants most frequently gathered by the three Bhotiya sub-communities. The study concludes with a consideration of the present and future of the indigenous knowledge (Mbuni et al. 2020).

14.3.1 Assessment of Declining Crop Diversity

When it comes to agricultural crops, quantifying their variety and ranking them based on their rarity, endangerment, or extinction is a challenging task. As a rule, planting occurs between 1800 and 2000 metres above sea level (masl), with the two major crops seasons being Kharif and Rabi. Summer crops (planted between April and October) are grown only at higher altitudes (>2000 masl). Several recent shifts in traditional Himalayan agroecosystems can be attributed to factors such as inefficient technical advancements, population pressure, land tenure policies, market forces, economic expansion, improper social welfare and environmental protection programmes, etc. The debate over sustainable development in the Himalayas is dominated by negative trends in the region's agroecosystems, such as falling crop yields and the extension of agriculture onto marginal territory. In an effort to make ends meet, traditional societies in the Himalayas have reduced fallowing between crops, expanded farming onto steep slopes and marginal soils, and substituted less nutritious modern values for their staple foods.

Table 14.1 A list of the most collected a plant from the wild in the Central Himalayas and their uses

Scientific name	Local name	English name	Part used	Cure/use	Mode of uses	References
Aconitum bulfouri Stapf (Ranunculaceae)	Metha	Monkshood	Tuber	Snakebite, infectious wounds	Very poisonous, used to cure snakebites. A paste is made from the tuber, and this is applied to the affected area. It is equally effective in curing wounds in domestic animals.	Sharma and Gaur (2012)
Aconitum heterophyllum Wall. ex Royle (Ranunculaceae)	Atis	Atis root	Roots, tuber	Headache, fever, stomachache, diarrhea,	A decoction of the tuber is used to treat fever, stomachache, diarrhea, and dyspepsia, while the root extract is used to treat headaches. An effective tonic can be made by boiling it with water.	Buddhadev and Buddhadev (2017)
Allium stracheyi Baker (Alliaceae)	Jimbu	Keer	Above-ground part	Stomachache and spices/ condiments	The powdered combination of ghee (purified liquid butter) and the root of Saussurea costus is used to treat stomach pain. A seasoning component of the regional pulses and vegetable dish farran.	Gautam (2019)
Allium humile Knuth (Alliaceae)	Sedum	(Not available)	Above-ground part	Stomach ache and spices/ condiments	Uses are similar to those of *Allium stracheyi*.	Lingfa (2012)
Angelica glauca Edgew (Apiaceae)	Choru	Angelica	Root	Dysentry, body pain, condiments	The root can be used as a spice or condiment, and a decoction can alleviate stomach pain and diarrhea caused by the cold.	Kumar et al. (2022)
Arnebia benthamii (Wall. ex G. Don) I.M. Johnston (Boraginaceae)	Balchhari	(Not available)	Root	Hair tonic	After 2–3 days in water or hair oil, the roots (fresh or dried) will no longer cause hair loss.	Rather et al. (2018)

(continued)

Table 14.1 (continued)

Scientific name	Local name	English name	Part used	Cure/use	Mode of uses	References
Berberi saristata DC. (Berberidaceae)	Chotru	Barberry	Root, bark	Eye diseases, headache	Eye disorders can be treated with a decoction created by boiling the root in water, while headaches can be alleviated with a paste made from the fresh root.	Komal et al. (2011)
Bergenia ciliata (Haw.) Sternb.	Shilphori	(Not available)	Leaves	Traditional tea	Like tea but made from dried leaves that have been ground into a powder.	Ahmad et al. (2018)
Betula utilis D. Don. (Betulaceae)	Bhojpatra	Himalayan silver birch, or Indian paper birch	Resin	In traditional tea; cold and cough	Powdered bole resin that has been dried and stored is a critical ingredient in traditional namkeen tea.	Safdar et al. (2017)
Cannabis sativa L. (Cannabaceae)	Bhang	Marijuana	Leaves, seeds and bark	Stomach pain, burn, muscular pain	Small pallets are prepared while crushing the young leaves by hand; these are dipped in the water, and the extract is used to cure stomach pain and kill stomach worms. Oil extracted from the seed is used to treat burns and muscular pain. Seeds are edible.	Andre et al. (2016)
Carum carvi L. (Apiaceae)	Kalajeera	Caraway	Seed	Stomach pain, spices/ condiments	Constipation can be alleviated by consuming a mixture of crushed seed and sindi salt (senda namak). The seed is mainly used as food but has culinary applications.	Goyal et al. (2018)
Cedrus deodara (Roxb. ex D. Don) G. Don (Pinaceae)	Devdar	Himalayan cedar	Wood	Skin disease of sheep and goat; wounds and cuts	The wood is used to make oil that is applied topically to treat makku illness, a skin condition found in sheep and goats, as well as demodectic scabies. Oil is commonly used as a topical treatment for cuts and scrapes. To effectively treat intestinal worms, ingest one to two drops of oil twice daily.	Bisht et al. (2021)

Dactylorhiza hatagirea (D. Don) Soo (Orchidaceae)	Hathazari	(Not available)	Tuber	Wounds, fever, dysentery, bilious fever	Extraction from the tuber is used to treat fever and as a tonic because of its ability to speed up the body's natural healing processes after injury. The patient is given a tuber decoction flavored with sugar, milk, and spices. Dysentery and bilious fever are both treatable with a tuber extract.	Pant and Rinchen (2012)
Fagopyrum esculentum Moench (Polygonaceae)	Banoggal/ janglioggal	Buckwheat	Leaves/ youngshoot	Headache, fever	Headaches can be alleviated by applying a paste made from the leaves, and fevers can be quelled by eating the leaves after they have been cooked in ghee. Vegetables can also be made from the leaves.	Al-Snafi (2017)
Hippophae rhamnoides	Amesh	(Not available)	Fruit	Cold and cough;	The ripe fruit is juiced, and the juice is cooked with sugar to create medicinal syrup for colds and cough.	Ciesarová et al. (2020)
Indigofera heterantha Wall ex Brandis (Fabaceae)	Sakina	(Not available)	Root	Anthelmintic	A decoction of the root is considered an anthelmintic by villagers.	
Juglans regia L. (Juglandaceae)	Jangli akhhrot	Common walnut	Fruit/seed	Itching, stomach ache pain; dying toothbrush;	Oil extracted from the seed kernels is used to cure external body itching and stomachache. The bark is used to clean the teeth, and the outer cover of the fruit is used for dyeing woolen cloth.	Wani et al. (2016)
Juniperus indica Bertol. (Cupressaceae)	Bhitaru	Juniper	Leaves	Religious/ domestic	Dhoop is made from the dried leaves, whereas balma wine is fermented with a leaf extract.	Rawat and Everson (2012)

(continued)

Table 14.1 (continued)

Scientific name	Local name	English name	Part used	Cure/use	Mode of uses	References
Meconopsis aculeata Royle (Papaveraceae)	Kanda	Queen of Himalaya flower, or blue poppy	Root	Wounds	A paste of the root is used to cure infected wounds and cuts.	Ganaie et al. (2016)
Megacarpaea polyandra Benth. (Brassicaceae)	Barmao	(Not available)	Root, leaves	Stomach ache, dysentry; vegetable	A decoction of the root helps to prevent stomach disorders. The dried leaves fried with *ghee* are a good remedy for dysentery. The dried leaves are used as a vegetable during lean periods.	Singh et al. (2021)
Morchell aesculenta (L.) Pers. ex Fries (Morchellaceae)	Guchhi	Commonmorel (edible fungus)	Fruiting body	Commercial; cold	Collected from the forest between April and June and sold in the market. A decoction of dried fruiting body is helpful in the treatment of colds and coughs.	Raman et al. (2018)
Nardostachys grandiflora DC. (Valerianaceae)	Mashi	Indian nard, or spikenard	Root	Burn, joint pain, rheumatism	Burns can be treated with a root extract, while ghee alleviates joint discomfort and rheumatism. The dried root is ground into a paste and used in place of dhoop.	Gautam and Raina (2013)
Nepeta discolor Royle ex (Lamiaceae)	Khirku	Calmint	Leaves	Wounds, eye diseases, asthma	Make a paste with fresh leaves to treat cuts and scrapes. A powder made from dried leaves, milk, and honey is used to treat eye disorders. Patients with asthma are given a decoction by boiling the dried leaves in water.	Sharma et al. (2021)
Origanum vulgare L. (Lamiaceae)	Janglitulsi	Wildmarjoram	Leaves	Fever, cough, skin diseases	A fresh leaf extract is used to treat fever and cough and to eliminate dangerous intestinal worms. As an ointment, it treats a variety of skin disorders.	Naquvi et al. (2019)
Paeonia emodi Wall. ex Royle (Paeoniaceae)	Chandra	Himalayan peony	Leaves	Blood purifier, dysentery, colic	The blood-cleansing effects of the dried leaves can be enjoyed in the form of a vegetable. Dysentery and colic can be alleviated by eating ghee-fried dry leaves.	Joshi et al. (2017a, b)

Picrorhiza kurooa Royle ex. Benth. (Scrophulariaceae)	Katuki	(Not available)	Root	Jaundice, stomach pain, dyspepsia, dysentry.	Use a decoction made from the root to cure jaundice and stomach pain. Dyspepsia and dysentery can be treated using a paste made from the root, sugar, and kesar flower.	Debnath et al. (2020)
Pleurospermum angelicoides (DC.) C.B. Clarke (Apiaceae)	Chippi	(Notavailable)	Root	Typhoid fever, stomach ache, body pain, dysentery; spice	The root is ground into a powder with the seeds of jeera and black piper to cure typhoid fever, stomach pain, and body pain, and is also given to children suffering from dysentery due to cold.	Chandwani et al. (2022)
Prunus persica, (L.) Batsch (Rosaceae)	Kirol	Peach	Seed	Massage; stomach pain	The seed kernels are pressed for oil, massaged into the body throughout the winter to increase circulation and maintain a comfortable temperature. The oil can be consumed and is also used for treating digestive issues.	Kant et al. (2018)
Potentilla fulgens Wall. ex Hook (Rosaceae)	Bajradanti	Silverweed	Root	Toothache	Pain from an infected tooth can be alleviated by applying a paste made from the root of the plant directly to the gums.	Kumar (2021)
Rosa webbiana Wall. ex. Royle (Rosaceae)	Sedum	Himalayan musk rose	Ripefruits	Eye disease	The fruits can be eaten and an ointment made from the bark can treat eye infections.	Jan et al. (2021a, b)
Rhododendron campanulatum D. Don (Ericaceae)	Awom	Rhododendron	Leaves	Wounds, cold and cough	An antiseptic paste from fresh leaves and mustard oil is applied to cuts and scrapes. Cold and cough symptoms can be alleviated by taking a powder made from dried, ground-up leaves (given to the patient with boiled water).	Singh et al. (2018)

(continued)

Table 14.1 (continued)

Scientific name	Local name	English name	Part used	Cure/use	Mode of uses	References
Rheum australe D. Don (Polygonaceae)	Dholu	Rhubarb	Root, shoot	Boils, wounds; condiment; dying	The young shoots are pickled, and the bark powder is used to color woollen cloth by mixing it with tejab. The paste derived from the root is used to cure boils, wounds, and cuts.	Rokaya et al. (2012)
Saussurea costus (Falc.) Lipsch. (Asteraceae)	Kut	Costus, kuthrooth	Tuber	Stomach pain, toothache, typhoid fever	Stomach aches, toothaches, and typhoid fever can all be alleviated by drinking a decoction made from the tuber. It has long been held that keeping even a small piece of a tuber inside one's home can deter snakes from making a home for themselves.	Pandey et al. (2007)
Saussurea obvallata (DC.) Edgew. (Asteraceae)	Brahmkamal	(Not available)	Flower	Religious	Flowers are generally offered to deities by the buffer-zone villagers on Janmashtami and Nandashtmi.	Semwal et al. (2020)
Seriphidium maritimum (L.) Polj (Asteraceae)	Dronapati	(A type of Worm wood)	Whole plant	Religious	To make dhoop, dried leaves are powdered and combined with oil of kirol.	Azimova and Glushenkova (2012)
Smilacina purpurea Wall. (Convallariaceae)	Puyanu	(Not available)	Leaves	Vegetable	Collected in large quantities as vegetables and sun-dried for futureconsumption, particularly during the lean period. It helps to keep the body warm in winter.	Misra et al. (2008)
Taxus. wallichiana (Zucc.) Pilcher (Taxaceae)	Thuner	Himalayan yew	Bark	Traditional tea	Namkeen tea is made by boiling tree bark powder with water and adding salt and ghee; it is traditionally used in the winter to keep the body warm. The Bhotiya people are the biggest fans.	Juyal et al. (2014)

Table 14.2 Traditional medicinal plants and formulations used by Himalayan ethnic people in the treatment of several disorders

Plant species	Ethnic/common name	Composition and use
Pleurospermum angelicoides (DC.) C.B. Clarke	Chippi	*P. angelicoides* (root) 50 g, cumin seed (10 g), and black pepper (7–8 grains) crushed together, boiled (5–10 min) in 200 ml water over moderate heat, and then allowed to cool. A remedy for fever.
Dactylorhiza majalis (Rchb.) Hunt & Summerh.	Hathazari, Hardy orchid	50 g tuber of *D. majalis* is boiled with 200 ml water; the decoction is then blended with one teaspoon of sugar and 10 g coriander seeds and simmered\ s5–10 min over moderate flame together with 200 ml water. It is a fever reducer.
Origanum vulgare L.	Jangli tulsi, Wild marjoram	50 ml extract of fresh leaves, combined with 10 g honey and 2–3 g powder of the root of *P. angelicoides*. This concoction is eaten to cure fever. Dosages administered four spoonfuls (3) two spoonfuls (3) 10 g (2) (2)
Aconitum heterophyllum Wall. ex Royle	Atis	The root paste is applied to the forehead to cure headaches.
Cicerbita macrorhiza (Royle) Beauv	Karatu	When applied topically to the forehead, the paste made from the root can alleviate headache pain, and ingesting the juice of fresh leaves is also effective.
Tanacetum tomentosum DC.	Goggal	Five grams of the raw root are ground into a paste combined with 50 ml of *Berberis aristata* infusion. When applied to the forehead, this ointment can alleviate headache pain.
Nardostachys grandiflora DC.	Jatamansi, Indian nard	A 10 g paste of root mixed with 50 g ghee (purified semi-liquid butter) is cooked slightly for 5 min. To alleviate rheumatic symptoms, the combination is applied topically to the afflicted areas of the body.
Cirsium verutum (D. Don) Spreng.	Biskanara	100 g root is boiled with 500 ml water to make the decoction of 50 ml, blended with one to two spoonfuls of *Cedrus deodara* oil and put externally on joints to relieve rheumatism.
Juniperus communis L.	Thailu; common juniper	For 2–3 min over a moderate flame, 50 g of fresh bark paste is heated with 200 ml of oil pressed from Prunus persica seed kernels. Rheumatism sufferers who apply this ointment to their joints may get relief from their symptoms.
Picrorhiza kurooa Royle ex Benth.	Katuki	For best results, let the 50 g of root steep in 200 ml of water for 2–3 h before adding the honey. To ease abdominal pain, take this.
Megacarpaea polyandra Benth.	Barmoa	100 g dried *M. polyandra* leaves are cooked in two to three tablespoons of ghee with 10 g bark powder of Taxus baccata. Used for the relief of stomach pain.

(continued)

Table 14.2 (continued)

Plant species	Ethnic/common name	Composition and use
Cannabis sativa L. bang	Marijuana	Crushing the young leaves by hand and soaking them in the mildly warm water (200 ml) for up to 20 min with the addition of 2 g sindi salt is the first step in making little pallets (50 g) (Senda namak). Ingesting the drink alleviates abdominal discomfort.
Saussurea obvallata (DC.) Edgew	Brahm kamal	An infusion of 100 cc of dried leaves seasoned with half a teaspoon of salt. Boils, cuts, and wounds can all be treated by applying a few drops of this to the affected area.
Rheum australe D. Don	Dolu/tatri; rhubarb	D. majalis decoction (10 ml) is added to 50 g of fresh root paste, and the mixture is cooked for 1–2 min over a moderate flame. This is applied to the affected region.
Nepata discolor Royle ex Benth.	Khirku; Calminth	150 ml decoction of dried leaves is combined with two to three spoonfuls of honey. Used to treat TB.
Picrorhiza kurooa Royle ex Benth.	Katuki	It takes one night of steeping 50 g of dried root and three tablespoons of sugar in 200 ml of water. To treat jaundice, the mixture is consumed the following day.
Saussurea costus (Falc.) Lipsch.	Kuth root	100 ml root decoction of *S. costus* is mixed with two spoonfuls of honey and 50 ml milk and is drunk to cure jaundice.
Calanthe tricarinatha Lindl.	Garurpanja	Jaundice can be treated with a 100 ml decoction of the dried root, along with one spoon of sugar and 10–20 ml of milk.
Berberis aristata DC.	Chotru; barberry	In order to treat an eye infection, a decoction (juice) made from 100 cc of root is used.
Betula alnoides D. Don	Katbhoj; Himalayan birch	In order to treat eye disorders or infections, 100 g of ash from burnt bark is combined with two spoonfuls of ghee to form a paste that is then applied to the eyelid.
Ribes himalense Royle ex. Decne.	Darbag; Himalayan current/ gooseberry	A paste of dried roots (10 g) is combined with ghee (one teaspoon) and warmed slightly. Before going to bed, this is placed on the eyelid to treat eye disorders.
Pinus wallichiana A.B.	Jackson kail; blue pine/Himalayan pine	Fractured limbs can be bandaged with mildly warmed *P. wallichiana* resin. Betula utilis bark is applied topically soon after an injury, alleviating discomfort and speeding recovery from a sprain or fracture.
Saussurea obvallata (DC.) Edgew.	Brahm kamal	Combine 200 ml of root or leaf decoction with two to three teaspoons of *Cedrus deodara* oil. Pain is relieved when this is rubbed onto the affected area.

(continued)

Table 14.2 (continued)

Plant species	Ethnic/common name	Composition and use
Rhododendron campanulatum D. Don	Awon; rhododendron	100 g of fresh leaf paste and three teaspoons of mustard oil and cow dung ash. To treat a broken bone, this is warmed slightly and used like a plaster before being wrapped with a thin cloth. It relieves pain and speeds up the healing process.
Dactylorhiza majalis (Rchb.) Hunt & Summerh.	Hathazari; hardy orchid	Women typically take a tonic consisting of a 200 ml decoction of the *D. majalis* tuber flavored with 200 ml milk and two spoonfuls of sugar right before giving birth.
Paeonia emodi Wall. ex Royle	Chandra; Peony	Betula utilis resin is combined with 10 g of dried leaves fried in three teaspoons of ghee (known locally as bhuslisi). After giving birth, ladies eat this to strengthen their bodies.
Juglans regia L.	Jangli akhrot; walnut	Pregnant ladies massage oil produced from the seed kernels on their swollen legs after warming it slightly.

14.3.2 Agrodiversity, Agroecosystem Stability and Food Security

By increasing productivity through better use of available resources, boosting soil fertility when legumes are incorporated into the crop mix, decreasing the likelihood of pest, pathogen, and weed infestations, conserving soil nutrients, checking soil erosion, and producing a rich and balanced nutritional diet, the vast genetic resource base plays a crucial role in ensuring the long-term viability of the traditional agricultural system. Unlike the modern agricultural system, which relies heavily on imported materials, traditional farming makes use of only locally available resources. Villages in remote alpine regions face a significant risk of dependency on external inputs. There is a high likelihood of nutritional imbalance and significant vulnerability in a food system that relies on only two or three food crops. Food security in areas with less reliable climates may depend on perennial crops like millets grown using the traditional varied agricultural approach. There are 1.5–2.0 times as many protein molecules in traditional pulses (horsegram and *Vigna* spp.) as there are in wheat and two to four times as many in rice. If necessary, harvesting can be spread out over a period of 50–90 days for traditional crops such *Panicum miliaceum*, *Setaria italica*, and *Fagopyrum* spp. However, the potential yields of wheat and paddy are often not reached due to insufficient irrigation infrastructure and poor access to fertilisers and pesticides due to mountain-specific restrictions.

14.4 Health Benefits of Himalayan Ethnic Foods

The Himalayas span over 2500 km from the Indus Trench below Mt. Nanga Parbat (8125 m) in the West to the Yarlungtsangpo-Brahmaputra gorge below Mt. Qomolangma (8586 m) in the East, taking in the territory in India (Jammu and Kashmir, including Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, the Darjeeling hills, Arunachal Pradesh). More than 65 million people, representing over 200 different cultural groups, live in the Himalayan regions of India, Nepal, Bhutan, and Tibet.

Indian Hindus are the dominant religious group in the lower and middle Himalayan valleys, while Tibetan Buddhists have a stronghold in the region's high mountains. The Ladakh people are primarily Buddhist (Tibeto-Mongoloids). Hindus from Nepal and Buddhists with Tibetan roots make up Sikkim's diverse population. There are cultural similarities between Arunachal Pradesh and China's Yunnan province; nonetheless, most of the population in the state's northern area is of Tibetan descent.

Various biological zones according to the height or altitude of the Himalayas support a wide variety of plant, animal, and microbial life. Numerous species of shrubs, herbs, bryophytes, pteridophytes, and lichens can be found in the alpine meadows, which extend from the southern tropical monsoon rain forest or "saal" forest (*Shorea robusta*) to the top timberline at 4000–4500 m (Suyal et al. 2021).

Roti, rice, dal, chutney, pickle, beans, legumes, and meat, chicken, or fish make up the foundation of Indian cuisine and the diet of people living in Himalayan region also consists of this. These may also include several other elements, some of which may be exclusive to a given location, although enumerating all of those elements would be difficult in this space. It is now apparent that most people eat a healthy, well-balanced diet consisting of carbohydrates, lipids, fiber, and proteins daily. Low in calories and high in healthy fats, protein-rich foods like curd, beans, lentils, chicken, fish, and meat are a great addition to any diet. It is safe to say that the average Indian diet includes weight-loss-friendly sources of excellent carbs, natural protein, and resistant starch.

The people of the Himalayas have adapted to their climate and surroundings by creating unique regional cuisines. Consumption of such foods has been ingrained in societies for millennia, and societies have adapted to rely on them for survival. People who live at high altitudes (>2500 m) have adapted to eating less vegetables and more meat because these foods thrive in dry, cold conditions. There is a greater variety of foods available between 2500 and 1000 m in altitude, including rice, maize, vegetables, milk, and meat. Ethnic foods contain substances that are beneficial to health, such as antioxidants, antimicrobials, probiotics, bio-nutrients, and others. Traditional cultural and ethnic foods are losing popularity because of the negative impacts of fast urbanisation, development, and the advent of commercial ready-to-eat foods. The value of local traditions and the biological relevance of the foods they eat should be made clear to the people.

Age-old ethnic fermented foods are associated with native microorganisms that cause essential biotransformation of the substrates, contributing a wide range of desirable properties. These include making foods tasty, preserving foods, enriching the diet with improved flavour and texture, ensuring food safety by antimicrobial properties, enhancing nutritional supplements, and promoting probiotic and several health-promoting properties.

Sixty-four percent of the 175 wild plants used by Himalayans for nutrition are fruits or seeds, 18% are greens, and 10% are flowers or buds. Some plants are harvested for their medicinal properties, while others are cultivated for their colours, oils, or fermented foods and drinks. All of these peoples have an interest in using wild plants for a wide range of applications. There is a danger of extinction due to the widespread commercial exploitation of medicinal plants including Spondias axillaris, Machilus edulis, Baccaurea sapida, Eriolobus indica, Elaeocarpus sikkimensis, Bassia butyracea, and others.

Fermented foods and beverages are those whose production involves the controlled development of microorganisms and the subsequent conversion of raw materials into final goods via enzymes. Fermentation has long been used to preserve various foods, including meat, fish, dairy, vegetables, soybeans, other legumes, cereals, and fruits (Voidarou et al. 2020). The method of Lacto-fermentation is used to remove bitter phenolic compounds from foods such as olives, making them edible (Swain et al. 2014).

There are two main approaches to fermenting food. First, there are "wild ferments" or "spontaneous ferments" like sauerkraut, kimchi, and some fermented soy products, in which the bacteria are already present in the raw food or processing environment. Culture-dependent ferments are foods that require a starter culture to ferment (Lee and Jeon 2015). Backstopping is the process of executing a culture-dependent ferment by adding a small amount of a previously fermented batch to the uncooked item, such as sourdough bread. Fermentation can be induced naturally or using carefully selected commercial starters; the latter helps standardize the final product's organoleptic aspects.

Lactic acid bacteria create bioactive peptides and polyamines, which may improve cardiovascular, immune system, and metabolic health (this is true for fermented meals made with or without dairy). Patients with functional bowel disorders like irritable bowel syndrome may be more tolerant of fermented foods like sourdough bread and fermented soybeans because these processes reduce the concentrations of phytic acid and fermentable carbohydrates (e.g., fermentable oligosaccharides, disaccharides, monosaccharides, and polyols) (Melini et al. 2019).

More than 400 different types of common, unique, artisan, exotic and rare ethnic fermented foods and alcoholic fermented beverages are consumed as side dish, staple foods, curry, savoury, alcoholic drinks, pickles, soup, and condiments by the multiethnic Himalayan people due to diverse geographical coordinates and ago-climatic variations. Interestingly, the Himalayan fermented foods cover all types of available substrates ranging from milk to alcohol, soybeans to cereals, vegetables to bamboo, meat to fish, etc., and are grouped as fermented soybeans, fermented non-soybean legumes, fermented vegetables and bamboo shoots, fermented cereals, fermented milk, fermented/preserved meats and fish, consortia of microorganisms in the form of uneatable dry artisan starter culture for production of various alcoholic beverages and distilled liquor. The overall number of Himalayan fermented foods looks large; however, most of the fermented foods, based on major raw substrates, are similar in nature with slight variations in traditional preparation methods during natural fermentation, culinary practices and mode of consumption (Tamang 2022).

In addition to providing and preserving large quantities of nutritious and wholesome meals, fermented foods also offer a wide variety of tastes, smells, and textures that enhance the human diet. They produce fermented and sourdough bread, beer, vinegar, pickled vegetables, sausages, cheeses, yogurts, meat-flavored sauces, and pastes made from vegetable protein amino acids/peptides and alcoholic beverages. Edible microorganisms create enzymes (such as amylases, proteases, and lipases) that hydrolyze the polysaccharides, proteins, and lipids contained in the food substrate, resulting in harmless products with flavors, smells, and textures that are pleasing to human taste buds (Tamang et al. 2016).

A wide variety of fermented and non-fermented ethnic foods and alcoholic beverages originate from the Indian Himalayan Region (IHR). Traditional cuisine and a wide variety of cultural practices are hallmarks of the several indigenous groups that make up IHR. Alcoholic beverages have long been a staple at the ethnic people of the IHR's many social, cultural, and religious gatherings due to their significant ritual significance. Alcoholic beverages brewed at home are part of the social and cultural fabric of India and other parts of the world. Because different regions have variable availability of raw materials, the methods and ingredients used to prepare alcoholic beverages also vary. Most fermented beverages are cereal-based, while a wide variety of plants and fruits are also used as key raw materials, each contributing to the beverage's distinct flavour profile. There is evidence that suggests some of the plant elements used in traditional alcoholic beverages may also have nutraceutical and medicinal benefits. This property has the potential to add value to the commercialization of traditional alcoholic beverages, which in turn could help the rural economy (Rawat et al. 2021).

About a third of the average global diet consists of fermented foods. Cereals are a significant diet across the Indian subcontinent, Asia, and Africa and are an ideal substrate for fermented foods. Fermentation can alter the food's texture, flavor, appearance, nutritional value, and safety. Increased flavor and texture, increased shelf life from the production of acidulants, alcohol, and antibacterial compounds, microbial synthesis of essential nutrients, enhanced digestibility of protein and carbohydrates, elimination of antinutrients and natural toxicants, inactivation of mycotoxins, and shorter cooking times are just some of the potential benefits of fermentation (Tsafrakidou et al. 2020).

When grains are left to ferment in their natural environment, their nutritional value and lysine availability are enhanced. It is hypothesized that bacterial fermentations, including proteolytic activity, may increase the biological availability of essential amino acids more than yeast fermentation, which predominantly breaks down carbohydrates. Cereals lose some of their starch and fiber when fermented.

Fermentation is not likely to alter the product's mineral content; nonetheless, the destruction of chelating compounds such as phytic acid during fermentation increases minerals' bioavailability (Nkhata et al. 2018). The vitamin content of cereals can change during fermentation; however, the precise changes will vary depending on the kind of cereal, the fermentation technique, and the raw material used. During fermentation, B-vitamin content tends to increase. Flatulence-inducing phytates, trypsin inhibitors, and carbohydrates are reduced in a fermented combination of maize and soybean-corn meal. However, it has been shown that cereal fermentation with fungi like Rhizopus oligosporus releases bound trypsin inhibitors, increasing its effect. It is possible to completely detoxify aflatoxin B1 by breaking apart its lactone ring through microbial and lactic acid fermentation (Verni et al. 2019).

14.5 Conclusion

This article is a comprehensive overview of the indigenous knowledge of medicinal plants held by the peoples of the Central Himalayas. This body of information is inseparable from their way of life and cultural norms (or even three different ways of life, and three slightly differing cultures). In the recent past, these have encountered several obstacles. The homogeneity of the individual communities is giving way to the heterogeneity of settlements, and the rules and procedures which have traditionally regulated these tribal people are crumbling. The younger generation, tasked with maintaining the culture of their ancestors, is challenging the validity of long-held beliefs and indigenous knowledge. There is a complex web of economic, social, and political elements, each contributing to perpetuating the problems at hand. Neighbors' historical function as "keepers" during times of distress or celebration is dwindling.

Change is also being driven by young people leaving rural and remote locations for plains, semi-urban, and metropolitan centers searching for work. Gradually, these young people give up their traditions and embrace modern society. The disappearance of natural woods is a further obstacle to preserving indigenous knowledge and customs. Many native plant and animal species have perished due to forest depletion brought on by several circumstances. The urgency of the necessity for documentation increases when one considers how these indigenous communities undergo profound social, economic, and cultural transformations.

Those of us in the academic community have no business slowing down the march of progress and innovation. However, we think it is crucial to document this information and not just to archive it; we want to ensure that it continues to exist and may be used in the future. Conservation requires the upkeep of the natural ecosystems and the social and cultural structures of the local population. However, doing so would violate the rights of the individuals affected. The only other option appears to be meticulously documenting the wisdom of the individuals who live in these communities.

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Chapter 15
Ayurveda and Traditional Foods to Supplement Nutrition in India

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15.1 Introduction

Traditional food knowledge (TFK) is the cultural heritage of sharing food, recipes, cooking skills through generations. These traditional food resources are supply essential nutrients to human and also can be regarded as biocultural attribute. To promote biocultural variety and increase food production, we need to focus on the importance of traditional food knowledge that directly improve the health of individuals and community ecosystems (Hancock 1985). Loss of cultural heritage is the primary issue of the community including lack of traditional food expertise and proper explanation of traditional knowledge. So this thrust area has recently attracted the academic research to explore the in-depth mechanism. Exploring the knowledge associated with traditional foods can be a method to express ethnic identity and help individuals to feel more connected to nature which could be a possible solution to reduce mortality and morbidity due to malnutrition or chronic diseases. To improve individual health, to facilitate eco-friendly living as well as ecological health, it is crucial to explore this information (Kuhnlein and Receveur 1996; Berkes 2012).

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Worldwide, many nations are facing a severe problem of food crisis and therefore, nutrition insecurity. About two billion people are suffering from micronutrient deficiencies, often known as hidden hunger, which make them more susceptible to several diseases (Ritchie et al. 2018). Food insecurity is more severe in many African and south Asian countries though these regions are affluent in plant diversity which often playa as the key sources of functional food. Many communities around the world depend on wild species as a source of food and medicines to eradicate their hunger and to treat various diseases (Duguma 2020). However, securing the food is insufficient to ensure ideal nutritional status which might end up with malnutrition.

Traditional foods are an essential source of bioactive substances, which boost our immune system and help to achieve the criteria of food and nutrition security. While trying to achieve food and nutrition security, many obstacles are coming, but possibilities exist. That requires only the availability and consumption variety of meals and access to food for all people, which can provide the key needed nutrients. The average daily calorie needed to consume is 2280 calories in India (Venugopal 1999). Since nutrition and food security are the two sides of a coin, consuming essential nutrients is more important than just taking calories. In many developing nations, undernutrition, malnutrition, and increasingly overnutrition are the serious issues they face. Several options exist to promote economic development through the promotion of nutrition security. Additionally, diets and health can be improved while having less of an impact on the environment by addressing food and production systems and gathering, storing, transporting, transforming, and distributing foods. Publications that emphasize initiatives supporting nutrition security in developing and underdeveloped nations and rising economies are covered by this Portal topic (Ingram 2020).

Food has always been essential to human biology and socio-culture since it gives us energy and nutrients. Millions of humans have been closely associated with traditional food sources, giving them access to a wide variety of meals and food products made from plants and animals and the ability to develop sophisticated environmental knowledge. Thousands of underutilized edible plant species are wild, semi-wild, or left out during domestication (Ray et al. 2020). Indigenous people commonly eat various uncultivated plants and their parts, such as green shoots, fruits, seeds, edible subterranean sections, and flowers.

Food supplements, which primarily consist of proteins, minerals, micronutrients, and numerous vitamins, improve the nutritional quality and offer rural and semi-urban people across all cultures and continents a cheap source of nutrition. The main reasons for recommending diverse diets are optimum nutrition, health, and general well-being. Tribal tribes and non-tribal populations living in rural and semi-urban areas worldwide have a long heritage of using traditional foods as a source of nutrition and medicine (Mahapatra et al. 2012).

A large part of the world population depends on forest and forest products for their livelihood and food security (Sunderland 2011). Functional food is a vital supplementary source of nutrition, medicine, and fiber; in addition to these values, some food sources are commercialized and offered as an income to the tribal generation part of the rural community (Feyssa et al. 2011; Sardeshpande and Shackleton 2019). In due course of time, functional food has become economically and therapeutically important. Now many nutritionally rich food sources have been identified and domesticated by the cultivators. Considering these facts, researchers worldwide have started intensive research on functional food sources to investigate their potential in the treatment of various diseases and to be documented these sources and their sustainable exploration for human welfare. Although ensuring enough nutrition and preventing hunger is crucial, there is a difference between the terms "food security," "optimal nutrition," and "absence of hunger and undernutrition."

Globally, the food and dietary system of developing and low-income countries (especially in Asian and African countries) are not in a position to deliver a balanced diet across society leading to micronutrient deficiency in more than two billion people, especially pregnant women and children (Mkambula et al. 2020). The deficiency of micronutrients is the most common contributor to unhealthy development, low mental ability, and increased mortality rate (Bailey et al. 2015). The process of food fortification can overcome this situation. Food Fortification or Food Enrichment is the additive process of one or more essential micronutrients in food. The most common staple food is used as a vehicle food, fortified with food sources with immense micronutrients such as iodine, iron, calcium, magnesium, zinc, folate, and various vitamins. It is to notify that food fortification practices to save the population from health risks such as iodine deficiency, vitamin deficiency, anemia, and neural tube defects (Liyanage and Hettiarachchi 2011). The primary goal of this review was to investigate the Traditional food knowledge and its values in the Indian Subcontinent and to determine the nutritional and therapeutic value followed by food-to-food fortification.

A fundamental human right is access to food. In fact, it's possible to consider having access to at least an acceptable quantity of wholesome food to be the most fundamental of all human rights. The ability of a person to obtain an adequate supply of wholesome food is known as their level of food security. The four fundamental parts that make up the idea of food security are referred to as the "*four pillars of food security*" depicted in Fig. 15.1.

(i) *Availability*: simply means that food is present in a community. The effectiveness of food production is closely related to this.
(ii) *Access*: Even if there is enough food available in a town, it won't matter much if people can't get to it. True food security is the ability to access sufficient quantities of nutrient-rich food.
(iii) *Utilization*: Not all food is created equally or in sufficient quantities. A high standard of food must be accessed in order to maintain food security.
(iv) *Stability*: Good food stability is the continuity of access, availability, and consumption of food over time. Any threats to this stability should be minimised, it is crucial to remember.

Fig. 15.1 Conceptual diagram illustrates the food security

15.2 Traditional Food Knowledge System – Approaches Towards Combating Nutritional Insecurity

The use of functional food as herbal medicine in Indian Ayurveda medicine may have employed herbs to treat various chronic diseases. The ancient Greeks and Romans also used functional food as a nutraceutical source. Galen established the model for subsequent western medicine, although Hippocrates' writings mainly include the preserved Greek and Roman medical traditions. Hippocrates recommended using a few raw herbs-based medications with exercise, rest, and a functional food-enriched diet. Traditional medicine is practiced by individuals in countries worldwide, including Chile (71%), India (65%), Columbia (40%), Australia (48%), France (75%), Canada (70%), United States (42%), Belgium (38%), China (40%), and 80% in African countries (Azmi et al. 2017).

Traditional foods are a valuable source of bio-resources and bioactive components, which help to maintain food as well as nutrition security; additionally, they boost the immune system. However, global agriculture has steadily become less diversified more intensified with only high yielding varieties of a few crop varieties. Only nine known plant species contributes more than 75% of the world's plant-derived energy (https://www.huc-hkh.org/webinar/traditional-foods-and-their-role-in-health-and-nutrition-security-in-the-hkh accessed 24 October 2022). Three crops such as wheat, rice, and maize contributes half of the dietary energy. Due to several factors such as changes in the landscape, urbanization, migration, and unanticipated climate change indigenous knowledge associated with traditional foods, cooking techniques and preservation strategies are gradually declining (Ghosh-Jerath et al. 2021). The promotion of traditional food crops has now received attention, and they are now referred to as "future-smart foods" due to their high potential for nutrition security, climate resilience, and agrobiodiversity.

Increasing dietary quality and lowering the prevalence of non-communicable diseases are two mottoes in the communities across the Pacific region's focus on achieving food and nutrition security goals. To address these issues, it takes context-specific research that considers links between change drivers, food systems, and how they affect diets and health (Hidalgo et al. 2020). In all its manifestations, malnutrition is a problem, while there has been a considerable improvement in child stunting, low birth weight, and exclusive breastfeeding. However, the world is still not on track to ending Hunger by 2030 or satisfying the world's nutrition goals. Diet quality is being highlighted as a vital relationship between nutrition and food security.To provide cheap healthy diets as part of the necessary efforts to eliminate all forms of malnutrition and Hunger, a new study of the price and affordability of healthy meals around the world has been introduced (FAO, IFAD, UNICEF, WFP and WHO 2018, 2020). According to the FAO 2020 data, 14.5% of Indians and roughly 11% of the world's population are undernourished. According to a report published by the Indian Council of Medical Research (ICMR 2020), malnutrition frequently occurs in rural and tribal communities and is a major cause of death for children under five (Narayan et al. 2019). The primary cause of malnutrition is a lack of suitable quantities of fresh fruits, vegetables, grains, legumes, milk, and meat. Fortunately, a large population's dietary needs may be supplied using a variety of traditional crops and food production techniques that have been around for a while (Adhikari et al. 2019).

Numerous studies have examined a variety of faces of malnutrition, including its relationship to food production and food security, efforts to reduce poverty, and socioeconomic issues like access to health care and women's educational status (Schultink 2015). SDG 2's goals are to end hunger, achieve food security and improvement nutritional value, develop sustainable agricultural crop production and recognize the connections between food and nutrition security (Bhavani and Rampal 2018). The production of food, which is necessary for nutrition security, makes agriculture an essential factor in ensuring appropriate nutrition (Pinstrup-Andersen 2006; Hoddinott et al. 2014). Numerous studies have empirically calculated that increased agricultural production significantly lowers malnutrition (Gulati et al. 2012; Headey et al. 2011). The most significant connection between agricultural growth and nutrition appears to be increased food production (Bhagowalia et al. 2012). According to the framework developed by UNICEF, the primary causes of child malnutrition can be divided into fundamental, underlying, and urgent issues. Malnutrition is primarily a result of a lack of access to health care, insufficient care, unhealthy living conditions, and household food instability. These causes are in turn influenced by fundamental variables such as socio-political, environmental, and economical factors. Poverty has a significant impact on each of these factors. According to the framework developed by UNICEF, illnesses and insufficient

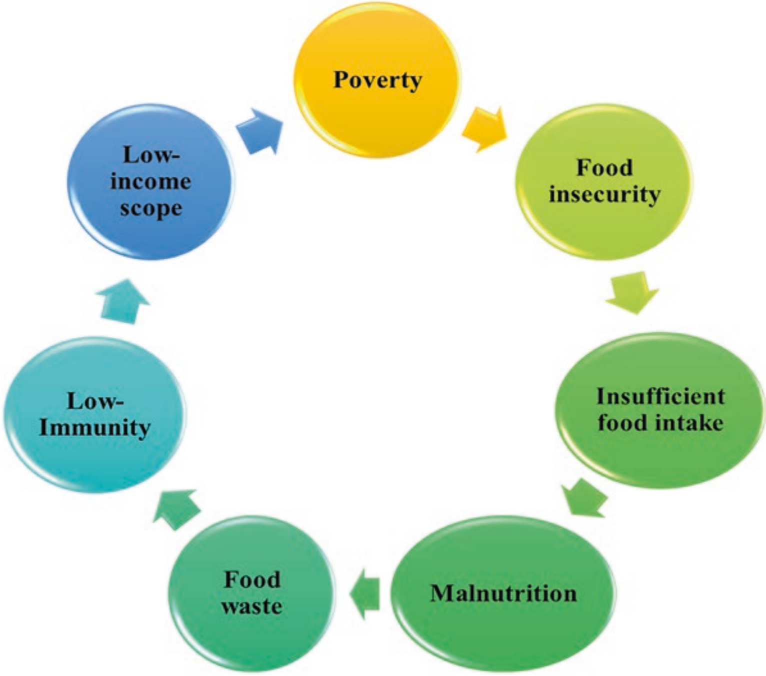

Fig. 15.2 Conceptual framework for undernutrition origins

nutritional intake can be categorized as the immediate causes of undernutrition. The interplay of these direct causes is what leads to the high morbidity and mortality rates in underdeveloped nations (Tontisirin and Gillespie 1999; UNICEF 1998). Inadequate nutrition throughout childhood causes long-term physical underdevelopment, raising the risk of developing chronic illness. The short-term effects of undernutrition in underdeveloped nations are nutrition-related health issues that cause maternal and child mortality due to recurrent infectious illnesses (Tarozzi and Mahajan 2007). This vicious cycle has been depicted in Fig. 15.2.

15.2.1 Functional Roles of Indian Traditional Foods

Traditional food systems around the world help to preserve crucial indigenous food as well as cultural food (Gibbon 2012). India is not an exception. Besides, it helps with a few health conditions like stomach upset, obesity, allergies, cardiovascular diseases, asthma, and diabetes, serving as a bridge between indigenous food and natural products as medicine. It guarantees marginal populations access to sufficient food, especially in low-income communities in the Himalayan region, where a large portion of the population—especially women—remains engaged in agriculture (Bisht et al. 2018).

Traditional functional foods are in line with the idea that food can serve purposes beyond just being a source of nutrition. The regular use of traditional functional foods serves as a fantastic illness prevention strategy. Functional properties of traditional foods of different regions of India have been represented in Tables 15.1, 15.2 and 15.3. Numerous health benefits associated with the consumption of functional foods have been shown by epidemiological randomised clinical trials conducted in various nations, including a improved heart health, decreased risk of cancer, a decrease in menopause symptoms, maintenance of urinary tract health, immune system stimulation, anti-inflammatory effects, improved gastrointestinal health, lowered blood pressure, preservation of vision, antiviral efficacy and antibacterial effect. Traditional functional food helps to maintain the health of the individual by preventing the major illness and thereby reducing the cost of health care. The Indian tradition has a long history of using spices in food as medicines to prevent and treat illnesses. Spices play a very essential role in digestive function (Weiss 2009). Another epidemiological study hypothesised that curcumin, the bioactive component of turmeric, one of the most common dietary and therapeutic substances used by the Indian population, was responsible for the significantly lower prevalence of neurodegenerative diseases, cancer, metabolic disease and, cardiovascular disease in India compared to the United States (Calabrese et al. 2010). Additionally, it is predicted that an adult in India consumes 50 g of garlic in a week and 80–200 mg of curcumin each day. Therefore, it is plausible to obtain a therapeutic dose by daily dietary consumption (Tapsell et al. 2006; Sainani et al. 1979). Accordingly the whole world realized the benefits of functional food during twentieth century and it is evidenced from ancient texts of Ayurveda that the India has realized this facts thousands of years back.

Nutritional problems remain a critical barrier to our nation's healthy and disease-free culture. Here traditional diets provide us a proper food containing a higher content of nutrients. Sadly, due to improvements in technology and food preparation, our civilization no longer consumes many of these ancient dishes. Health is being affected in the modern day due to rapidly changing eating patterns, the usage of canned food, chemical preservatives, and junk food. People who ate a natural diet of unprocessed foods were mainly free of ailments including obesity, infertility, mental illness, heart disease, autoimmune disease, and diabetes. Whole health is facilitated by traditional foods (Goel 2018). The variety of traditional and ethnic foods exhibits their positive health effects. Applying the combinatorial theory of food ingredients and combining traditional meals to attain higher health advantages will lead to sophisticated food habits during food processing. Most traditional food is prepared by the fermentation process, which is good for health due to the absence of sugar or gluten; for instance, it is free of gluten, caffeine, lactose, and antibiotics. Nutraceuticals could play a crucial role in nutritional biochemistry when examining them through the lens of nutra-epidemiology. The life cycle approach to nutrition vital to human health and well-being—becomes incredibly evident (Prakash 2016).

Table 15.1 Functions of some North-east Indian traditional foods

S. no.	Traditional foods	Ingredients	Direction of use	Treatment and benefits	Reference
1.	Rakthashali red rice (with red husk and grain)	Red puffed rice, rice ganja, Manni, and parched red rice, rice soup in addition to sugar, cow milk, or jaggery.	During the full moon, rice soup is kept for the absorption of radiation in the full moon and immediately have to take, resulting in it will activate of antibiotics and immunoglobulins present in milk	Allergies, skin conditions, issues with the uterus, neurological conditions, gastrointestinal issues, liver and kidney abnormalities, fever, infections, and in aiding lactation.	Hegde et al. (2013)
2.	The pulp of pumpkin with seeds	Mixed with herbal extracts such as mint, coriander, black pepper, ginger, and jaggery.	Ground to a paste with fresh red rice gruel and pulp of pumpkin with seeds in addition to black paper and jaggery	Cold, neurodegenerative disease, and fever	Hegde et al. (2013)
3.	Jaljeera-cumin seeds	Cumin seed powder with Jaggery, Black salt, lemon juice, mint leaves with water	Traditional Indian drinks, which was used to be stored in matkas wrapped with a wet cloth to keep it cool	Helps in digestion, keeps us hydrated, prevents anemia, improves vitamin C deficiency, burns calories	Pushpangadan et al. (2012)
4.	Root extract of *Decalepis hamiltonii* (Nannari sharbat)	Root powder, sugar, and water	Traditional beverage mixed with sugar and dried powder kept for soak for 12 h and boiled for 2 h	Stomach coolant, relief provider from constipation and acidity, also shows hepatoprotective and antioxidant activity	Aluri (2011); Srivastava et al. (2006); Srivastava and Shivanandappa (2010)
5.	Tambuli-soothing, healthy curd-based traditional dish	Mixed with udupi (Centella Asiatica, commonly known as Indian pennywort), Doddapatre (Borage leaves), Garlic, Ginger, Menthe (Fenugreek seeds)	Often served with rice before having sambar or rasam	Enhance skin health, detoxify the body, protect against colds, lessen arthritis pain, reduce stress and anxiety, treat some types of cancer, and improve digestion.	–

(continued)

Table 15.1 (continued)

S. no.	Traditional foods	Ingredients	Direction of use	Treatment and benefits	Reference
6.	Ondelaga pickle – Centella Asiatica Urb.	C. Asiatica leaf with N. arborists with onion bulb	Leaf and flower infusion prepared with onion bulb	Reduce blood pressure and for cardiac disease treatment and maintenance Kapha and pitta ratio	Prakasha et al. (2010); Shivakumar and Parashurama (2014)
7.	Fermented bamboo shoots- eup, curry, ushoi, rep, Gulai rebung, soibum, chutney, mesu, and ekhung	Bamboo shoots with thick coconut milk and fermented bamboo shoots with potato	Contains higher content of nutrition	Anti-cancer, antioxidant, anti-aging, antidiabetic, cardioprotective, weight loss, probiotics	Behera and Balaji (2021); Nongdam and Tikendra (2014); Chongtham et al. (2011)
8.	Tikhur sweets-Curcuma angustifolia rhizome or Indian arrowroot	Sugary delicacies like Jalebi, Halwa, and Barfi	Khoa, ghee, and arrowroot mixed and cooked sugar and water	For bone fracture, stomach-ache, fever, indigestion, renal stone, joint pain, peptic ulcer, leucorrhoea, and inflammatory conditions,	Shukla (2021); Shankar et al. (2014)

15.3 Ayurveda: The Indian Philosophy Behind Balance Diet

According to the ancient Indian medical system, Ayurveda, the management of nutrition in our body is crucial, and the entire human body is viewed as a product of food. According to Ayurveda, there is a connection between the body, food, and life factors which demonstrates how any disease can be cured, the treatment procedure, and the detailed mechanism of the healing process. Ayurvedic theories are that our body's physical, temperamental, and mental states all are influenced by the foods we consume. Therefore, a balanced diet must be followed daily to stay healthy. According to the Ayurveda, nutrients from the foods are absorbed by the body by digestion into rasa (plasma), and thereafter into blood, muscle, fat, bone marrow, reproductive organs, and bodily fluids. Traditionally, any kind of sickness is defined as an unbalanced state of the mind, body, and soul. Ayurvedic science offers a variety of well-researched, time-tested therapies for various ailments and employs various medicinal techniques, including Rasayana, Satvajaya, Shodhana, Shamana, Pathya vyavastha, and Nidan Parivarjan (Hotz and Gibson 2007; Ravishankar and Shukla 2008) (Table 15.4).

Ayurvedic medical experts usually treat any disease by combining various natural products or their own patented formulation with food and exercise. The balance

Table 15.2 Functions of some South Indian traditional foods

S. no.	Traditional foods	Ingredients	Direction of use	Treatment and benefits	Reference
1.	Rasam	Traditional South Indian cuisine includes a spicy soup called rasam.	Tamarind juice is typically used as the base, and then other ingredients such as Indian sesame oil, turmeric, tomato, chili pepper, pepper, garlic, cumin, curry leaves, mustard, coriander, asafoetida, sea salt, and water are added. Can have it with rice or soup	Appetizer, antipyretic, Anaemia, better lactation, Hypoglycaemic, laxative	Devarajan and Mohanmarugaraja (2017)
2.	Virgin coconut oil	Coconut milk	Can use as toppings in curries and frying also	Anticancer activity due to the presence of lauric acid	Famurewa et al. (2017)
3.	Idli	Rice and black gram dal	Fermented Black gram dhal and rice at the ratio of 1:2, used as batter which contains naturally occurring fermentation microorganisms obtained from sour buttermilk.	Healthy to heart and intestinal, abundant in prebiotics as a antibacterial, anticancer agents, antioxidant, anti-inflammatory, and reduced cholesterol	Reddy et al. (1982)
4.	Ambali	Finger millet-based fermented semi-liquid product	The preparation process involves combining finger millet flour with water to create a thick batter, which is then cooked and fermented.	Low resistant starch and high calcium	Ramakrishnan (1980)
5.	Ragi hurihittu	The flour of popped finger millet	Components of ragi hurihittu that take a while to degrade the cell wall are important for making foods high in fibre.	High in minerals and dietary fibres	Nirmala et al. (2000)

(continued)

Table 15.2 (continued)

S. no.	Traditional foods	Ingredients	Direction of use	Treatment and benefits	Reference
6.	Bale dandu palya	Banana stems	The stem is divided into bits, formed into cubes, and cooked before being seasoned with turmeric powder, chilli powder, salt, coriander, curry leaves, and these herbs.	Hypoglycaemic and weight reduction.	Bhaskar et al. (2010)
7.	Vazhai poo poriyal	Banana florets	Cut into small bits, the florets are boiled in water while being seasoned with green chile, mustard, and onion. Grated coconut is afterwards used as a garnish.	Diabetes and heart burn	Kumar et al. (2012)
8.	Jackfruit seed chutney	Jackfruit seed	The ingredients for this dish are grated coconut, chilli, onion, and cooked jackfruit seeds. For flavour, salt and lemon juice are also added and served with roti.	Intestinal microbial balance	Swami et al. (2012)
9.	Mango peel chutney	Mango peels whether ripe or unripe, are used to make chutney.	Mango peels, clove, mustard, chile, fenugreek seed, black pepper, curry leaves, and turmeric powder are used.	Rich sources of bioactive dietary fibers, carotenoids, vitamin C, and vitamin E	Ajila et al. (2007)
10.	Cheera thoran	Amaranthus leaves	Amaranth leaf-based dish eaten as a breakfast food. Boiling of chopped green leafy vegetables then salt and spices are added while cooking. After cooking can add grated coconut.	Good sources of oxalic acid, hence it should be avoided by patients suffering from kidney stones	Guil et al. (1996)

Table 15.3 Functions of some North-Indian traditional foods

S. no.	Traditional foods	Ingredients	Direction of use	Treatment and benefits	Reference
1.	Kadha	Black pepper, Saunf, Ginger, Mint leaves, Corriander, Rock candy, Tulsi, Bay leaf, Clove, and Cinnamon	Kadha prepared by decoction method after adding all of ingredients.	Helps to boost immune system, reduce weight, inflammation, fever, cold, cough, and blood pressure.	Maurya and Sharma (2020)
2.	Shrikhand	Traditional cool dessert	Dryfruits, saffron, flavouring agents, and hung curd with condensed milk.	Diarrhoea, inflammatory bowel illness, colon cancer, helicobacter, and pylori infection	–
3.	Ginna	Indian sweet dish prepared with colostrum, jaggery	Colostrum, a nutrient-rich fluid secreted by female mammals soon after giving birth	A natural anti-microbial substances that actively promote an infant's immune system's maturity	Uruakpa et al. (2002)
4.	Rabdi	Sugar, Saffron, condensed milk, cardamom, and dry fruits.	Sweet dessert made with condensed milk originated from Mathura, Uttar Pradesh and Varanashi state.	Useful in bones, teeth, helps to boostup immune system and lower blood sugar level.	Tiwari (2021)
5.	Panjiri	Sooji, wheat flour, melon seeds, ghee, powdered edible natural gum, ajwain, fig, coconut, and dryfruits.	Traditional northern Indian sweet dish "Laddoo" prepared by deep fried and grinded dryfruits and coconut with fried sooji, fig, wheat flour and powdered gum.	For diabetic patients, helps to reduce blood sugar, assist new mothers rebuild strength and also give them nutrients that are necessary for breastfeeding.	Brien (2013)

of the three "doshas" is typically considered before starting or in treatment. In living things, these three doshas are the physiological component. Ayurveda seeks to maintain a condition of equilibrium between the structural and physiological components, which denotes good health. The disease may result from any imbalance brought on by internal or external sources (Gordon et al. 2019). For example, according to Ayurveda, the treatment of diabetes (Fig. 15.3) will be like this- there are 20 different varieties of diabetes (prameha): 4 caused by Vata, 6 by Pitta, and 10 by Kapha (Gordon et al. 2019; Sridharan et al. 2011). However, Kapha doshaja is primarily responsible for diabetes (Prameha). Therefore, you can treat diabetes with Ayurveda in four different ways:

Depending on which body element predominates, *doshas* are split into three groups: *Kapha* (composed of earth and water, which is the sources of the greasing and structural energy), *pitta* (composed of fire and water, which is the sources of the strength of metabolism or digestion), and *vatta* (composed of space and air, which

Table 15.4 Ayurvedic knowledge of processes of functional foods

S. no.	Names of therapy	Treatment principle	Types of the technique used	Treatment impact on the body	References
1.	*Sodhana*.	A method of purification process where hazardous elements are eliminated from foodstuffs by the application of several unit operations	Virecana, Svedana, Nirvapana, Shoshana, Adhahpatana, Dhalana, Bharjana, Urdhvapatana, Bhavana, Sthapana.	Enhances the nutritious value of foods while also removing contaminants, also for the treatment of loss of appetite, infection, diabetes, nausea, skin disease, and epilepsy.	Belge and Belge (2012)
2.	*NidanParivarjan-*	Focuses mainly on avoiding identified disease-causing agents	*Aharatmaka* – dietary including heavy food, unhealthy food or overeating, *Viharatmaka* – regimens like lack of physical exercise, excessive sleep, or taking a bath after the meal, *Manasvyaparatmaka* – psychological issues like lack of anxiety, relaxation from tension and *Anya Nidana* such as sweet enema or heredity	Treatment of obesity and causative factors like heart disease, loss of appetite, breathlessness, snoring, joint pain, and difficulty sleeping.	Mawale and Pajai (2014)
3.	*Shamana-*	A palliative approach entails bringing imbalanced doshas (humor) back to equilibrium without compromising or hurting other doshas.	Starters, physical activity, digestive aids, exposure to sunlight, fresh air, and fasting are all used to balance the doshas.	Slows the signs of aging, boosts immune system strength, improves mental clarity and vigor, builds up the digestive system	Ravishankar and Shukla (2008)

(continued)

Table 15.4 (continued)

S. no.	Names of therapy	Treatment principle	Types of the technique used	Treatment impact on the body	References
4.	*Rasayana*	A rejuvenation medicine-based immunomodulator therapy. This treatment tries to increase the body's resistance to certain illnesses. Rasayanas, in general, function through three main pathways to enhance nutrition.	Srotas, Agni, and Rasa boosters. Rasa enhancers directly affect nutrients, Agni enhancers increase the capacity of digestion, and Srotas increase the flow of nutrients. Rasayana therapy involves the use of ashwagandha, curcumin, garlic, ginger, and neem, among other ingredients.	Exhibits anti-stress, adaptogenic, and memory-enhancing effects; these compounds delay brain aging and aid in neural tissue regeneration. Shows a significant effect on the heart, brain, skin, and eyes.	Chopra and Doiphode (2002); Singh et al. (2008)
5.	*Pathya vyavastha*	Dietary regulation plays a crucial role in maintaining biological activity and regulating emotional status and habits.	According to Ayurveda, the three pillars of life—food, sleep, and brahmacharya—are in order of importance. Therefore, a healthy diet should be considered, as it is necessary for excellent health and normal body functions.	Pathya Vyavastha primarily imparts information on the role of meals in various illnesses and stimulates digestion.	Tiwari et al. (2013); Masram et al. (2022)

is the sources of the movement's intensity). The three ayurvedic diet pillars are *Kedari Kulya Nyaya*, *Khale Kapota Nyaya*, and *Kshira Dadhi Nyaya*. These three concepts describe various aspects of digestion and how food is metabolized within the body (Nadkarni and Nadkarni 1954). The first rule of the ayurvedic diet is *Kedara Kulya Nyaya* which clarifies the first phases of digestion, in the presence of nature's components named fire, resulting in food converted into biological elements (nutrients), and finally will be circulated throughout the body in the *ahara rasa*. Now at the second step, named *Khale Kapota Nyaya*, the nutrient will be selected by Sapta Dhatus, which include Rasa, Rakta, Mamsa, Meda, Asthi, Majja, and Sukhra, and each dhatu decides on a particular nutrient as its substitute. For instance, *rasa Agni* selects plasma cells, mamsa cells (muscle cells), and protein molecules while *rakta Agni* selects iron molecules. Furthermore, at the third stage named *Kshira Dadhi Nyaya, the asthayi dhatu* (immature tissues) turns into *sthayi dhatu* (mature tissues), and immature blood cells called *rasa asthayi dhatu* convert into *sthayi dhatu* under the influence of *Rasa Agni* (matured blood cells) (Nadkarni and Nadkarni 1954). These three *doshas* regulate all physio-pathological, psychological, and biological processes of the body, mind, and awareness. Disease or disturbances in the body may result from an imbalance in these tri-*doshas*. For instance,

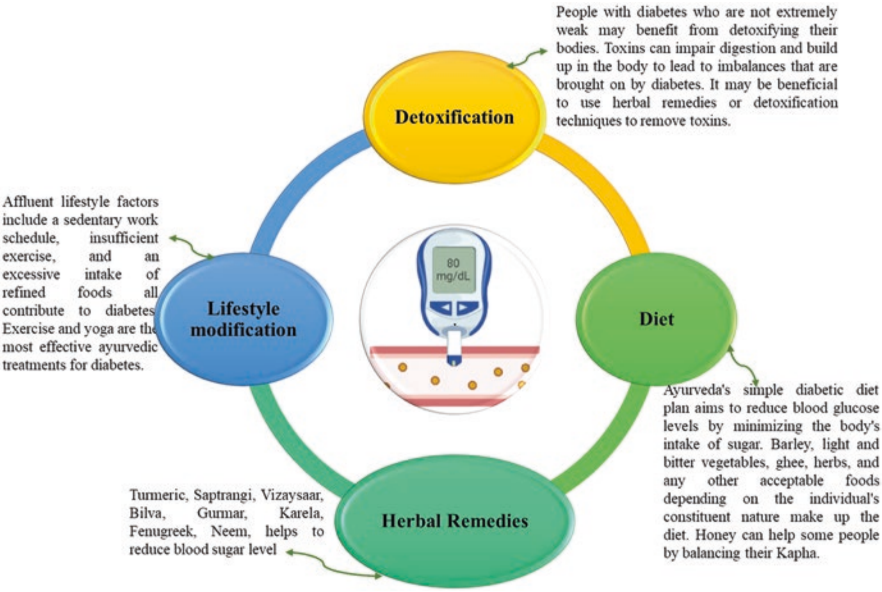

Fig. 15.3 Treatment of diabetes according to Indian traditional knowledge

though the fire element is encouraged in the body, the air element is encouraged, but the water element is required to manage the fire element. Here, the consumption of an adequate diet helps to restore equilibrium (*vatta*, *pitta*, or *kapha*) (Guha 2006).

15.4 Traditional Food and Knowledge Systems in the Treatment of Various Diseases

Indigenous people in rural and tribal groups have extensive ethnomedical knowledge of functional food (Mallick et al. 2020). The indigenous community relies on local plant resources directly or indirectly and is more aware of their medicinal, dietary, and food benefits. However, local health practitioners only transmit this information from one generation to the next; therefore, in the absence of proper documented knowledge, is often difficult to preserve the valuable knowledge and to pass down to the succeeding generations (Junsongduang et al. 2020). Now, it is essential to enlighten and spread the existing knowledge worldwide to ensure their best use, conservation, and scientific confirmation purposes; therefore, necessary to document the folk's knowledge of functional food.

Most functional food has nutritional benefits and is frequently used as medicine to treat various illnesses, including fever, colds, diarrhea, coughs, headaches, and stomachaches. In addition, they are also widely utilized as immune modulators and supplements for physical fitness (Sharma et al. 2017). Table 15.5 provides a

Table 15.5 Some traditional plants parts and their therapeutic uses in India

S. no.	Botanical name	Local name	Parts used	Uses	References
1.	*Achyranthes bidentata*, Blume Amaranthaceae	Dansh	Whole plant	Cough, fever, asthma, fistula, renal dropsy, skin rash, diabetes, diarrhea, tumor, indigestion, toothache, antifertility, pyorrhea, piles, anti-inflammatory, immune stimulant, snake bites and also used as Laxative	Hossain et al. (2013)
2.	*Protium serratum* (Burseraceae)	Indian red pear	Fruit	Mouth ulcer, antioxidant and anti-inflammatory	Hazarika et al. (2012)
3.	*Artemisia sacrorum*, Ladeb.	Kaparpatti & Jholpatti	Leaf & bud	Hair fall control	Prakash (2014)
4.	*Stixis suaveolens* (Capparacea)	Fragrant caper vine	Fruit	Heart disease, asthma, anti-inflammatory, fever, headache, and anti-arthritic properties	Islam et al. (2020); Konyak and Konyak (2020)
5.	*Adina cordifolia*, Hook. (Rubiaceae)	Haldu	Leaf, stem, bark & root	Antioxidant, anti-cancer, anti-diabetes, hepatoprotective, cytotoxic, antiamoebic, anti-inflammatory, anti-ulcer, and analgesic	Dalu et al. (2021)
6.	*Garcinia gummi-gutta* (Clusiaceae)	Malabar tamarind, Gambooge	Fruit	Diarrhea and anti-obesity	Bohra and Waman (2019)
7.	*Achyranthes aspera*, Linn. Amaranthaceae	Chinchilla	Whole plant	Gonorrhea and dog bite	Goyal et al. (2007)
8.	*Gnetum gnemon* (Gnetaceae)	Melinjo	Fruits	Dysentery of several types	Barua et al. (2015)
9.	*Crescentia cujeta* (Bignoniaceae)	Mexican Calabash, Morrito, Winged Calabash Jicaro, Kamandal	Fruits	Skin diseases, laxative, and cough.	Rahmatullah et al. (2010)
10.	*Adiantum venusthum*, G. Don. Adiantaceae	Hanshraj	Seed	Scorpion stings, headaches, wounds, cuts, and in hair fall control	Mubashir and Shah (2011)
11.	*Citrus macroptera* (Rutaceae)	Shatkora, hat- Khora	Fruit	Gastritis and kidney stone. Antihypertensive, antipyretic, and appetite stimulant potential	Aktar and Foyzun (2017); Paul et al. (2015)

(continued)

Table 15.5 (continued)

S. no.	Botanical name	Local name	Parts used	Uses	References
12.	*Agrimonia pilosa*, Ledeb. Rosaceae	Kafliya	Whole plant	Sore throat, abdominal pain, bloody discharge, headaches, eczema, and parasitic infections	Le et al. (2018)
13.	*Ajuga parviflora*, Benth. Lamiaceae	Ratpatia	Whole plant	Toothache, fever, diuretic, antimicrobial agents, and anti-inflammatory	Kumar et al. (2018)
14.	*Syzygium samarangense* (Myrtaceae)	Semarang rose-apple, wax apple, wax jambu, and Java apple	Fruits	Liver tonic and diabetes.	Khandaker and Boyce (2016)
15	*Parkia timoriana* (Fabaceae)	Petai Keruyung, Petai Kerayong, Kerayong, Kedawong	Fruits	Gastritis, diabetes and diuretic	Saleh et al. (2021)
16	*Melastoma malabathricum* (Melastomataceae)	Malabar melastome	Fruits	Gastritis, wound healing, and diarrhea.	Joffry et al. (2012)
17	*Allium wallichii*, Kunth. Alliaceae	Jangali Lasun	Root	In infection	Prakash (2014)
18.	*Aloe vera*, Linn. Alliaceae	Patquar	Leaf	Stomach problem wound healing	Sahu et al. (2013)
19.	*Althaea officinalis* Linn (Malvaceae)	Jangali hauli	Whole plant	Mild gastritis, oral and pharyngeal mucosa, skin burns, dry cough, insect bites, gastrointestinal tract and urinary tract complaints, catarrh, burns, inflammation, ulcers, abscesses, constipation, and diarrhea.	Husain et al. (2019)
20	*Artemisia nilagirica*, Pampanini. Asteraceae	Patti & Kunj Indian wormwood	Whole plant	Parasitic and helminthic diseases, neurological disorders, dermal infection and antifungal, antimicrobial, larvicidal, anti-inflammatory activities	Mohanty et al. (2018)

(continued)

Table 15.5 (continued)

S. no.	Botanical name	Local name	Parts used	Uses	References
21	*Abies webbiana*, Lindl Pinaceae	Talispatra	Leaves	In chronic obstructive pulmonary diseases, tumors, cough, hypochlorhydria, hiccup, amoebiasis, helminthiasis, vomiting, and mouth disorders	Vadivel et al. (2018)
22	*Acacia catechu*, Wild Fabaceae	Khair	Stem	Spongy and bleeding gums, leucoderma, stomatitis, leprosy, urinary disorder, diabetes, syphilis in urine problem & dysentery, psoriasis	Rashid (2015)
23	*Aconitum balfouria*, stapf. (Ranunculaceae)	Bishjahar	Root	Diaphoretic, febrifuge, diuretic, antirheumatic, anti-inflammatory, vermifuge, and antipyretic	Sharma and Gaur (2012)
24	*Acorus calamus*, Linn. Acoraceae	Banj	Root	Fever & toothache	Balakumbahan et al. (2010)
25	*Aesculus indica*, Colebr Sapindaceae	Pangar	Fruit	In stomach problem	Paudel et al. (2022)
26	*Allium stracheyi*, Baker. Alliaceae	Jambu	Whole plant	Cough-cold and jaundice	Chandrasekaran et al. (2020)

summary of the 26 most significant functional food worldwide, together with information on their distribution and medicinal properties.

15.5 Health-Promoting Factors & Nutrition Security

Energy and nutrition are provided by food, which has been at the center of human biology and sociocultural existence. For millions of years, people had a close relationship with the Wild, which provided them with a variety of foods and food items made from plants and animals and the opportunity to learn extensive environmental information. Thousands of underutilized edible plant species are wild, semi-wild, or left out during domestication (Ray et al. 2020). Indian floral elements' spectrum of functional foods has the potential to revolutionize our food systems (Hunter and Fanzo 2013; Powell et al. 2015).

Functional food supplements, primarily proteins, minerals, micronutrients, and numerous vitamins, improve dietary quality and offer rural and semi-urban people across all cultures and continents a cheap source of nutrition. The main reasons for recommending diverse diets are optimum nutrition, health, and general well-being. In rural and semi-urban areas around the world, tribal groups and non-tribal populations have embraced consuming functional foods (Mahapatra et al. 2012). During the twentieth century, researchers were mainly engaged in studying the nutrient composition and ethnobotanical perspective of plants, plant parts, and plant products, but later on, advanced studies got momentum due to the use of advanced tools and techniques, and investigations were initiated on pharmacological actions, food science, economic status and microbiology of the plants and their products (Sardeshpande and Shackleton 2019).

Functional food could be herbs, shrubs, small-height plants, trees, etc., as an integral part of an ecosystem and ecological balance (Ju et al. 2013). Functional food is being widely used as a traditional food resource for the people of remote and countryside areas (Mir 2014; Shivprasad et al. 2016; Kumar and Saikia 2020). Functional food has been established as a suitable source for many chronic diseases, including cardiovascular diseases, diabetes, obesity, and certain cancers (Deshmukh and Waghmode 2011). A large part of the world population depends on forest and forest products for their livelihood and food security (Sunderland 2011). Functional food is a vital supplementary source of nutrition, medicine, and fiber (Feyssa et al. 2011); in addition to these values, some species are commercialized and offer a source of income for the rural community (Sardeshpande and Shackleton 2019). Considering these facts, researchers worldwide have started intensive research on functional food to investigate their potential and document these wild edibles and their sustainable exploration for human welfare.

The high nutraceutical-rich value-added functional food supports human health and food security and provides rural and tribal populations with a source of additional revenue. These functional foods are excellent sources of natural antioxidants, phytochemical components, sugar, dietary fiber, proteins, minerals, and vitamins. Recent research suggested that a high nutraceutical-rich functional diet reduces the risk of diabetes, infections, cardiovascular problems, gastrointestinal diseases, and urinary illnesses. People live in poverty and cannot afford to eat a regular, balanced diet often get nourishment from the local indigenous food resources (Achaglinkame et al. 2019).

Functional foods are an excellent source of nutraceuticals and are essential for preserving human health (Donno and Turrini 2020). The macronutrients are those with concentrations of 1000–15,000 g/g of dry weight, such as calcium (Ca), nitrogen (N), phosphorus (P), magnesium (Mg), and potassium (K), while the micronutrients are those with concentrations 100–10,000 times lower than those of the macronutrients, such as chlorine (Cl), manganese (Mn), sodium (Na), copper (Cu), cobalt (Co), iron (Fe), and zinc (Zn) (Florkowski et al. 2009).

15.6 Future Prospective and Conclusions

Indigenous peoples' traditional food systems are filled with a variety of inadequately described and reported micronutrients in scientific literature. Due to the absence of scientific support, the information cannot be programmed for public health promotion, and health training is also included. However, indigenous peoples may be able to enhance their micronutrient status by using their traditional knowledge and various food options. The assistance of indigenous populations should be sought first by those working in the health sector who desire to utilize traditional knowledge regarding locally accessible food. Additionally, certain cuisines have gained popularity in specific regions based on the population's health, such as lactose sensitivity in Bengal, which has led to the popularity of lactose-free dairy sweets. In order to preserve knowledge on the processing, preservation, and dietary recommendations of traditional and ayurvedic foods for the benefit of both the Indian and international communities, a national research project in India is advised to scientifically document the health benefits of traditional and ayurvedic health foods across various regions.

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Conflict of Interest The authors declare that they have no conflict of interest.

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