Food Security and Nutrition

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FOOD SECURITY AND NUTRITION

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CHAPTER

1

Leveraging nutrition for food security: the integration of nutrition in the four pillars of food security

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1.1 Introduction

Food insecurity and malnutrition remain major global challenges, with more than two billion people experiencing moderate or severe food insecurity, 821 million people hungry (FAO et al., 2019), two billion suffering from micronutrient deficiencies (WHO, 2006b), and two billion adults suffering from overweight (of which two-thirds are obese), with obesity contributing to four million deaths annually as of 2018 (FAO et al., 2019).

Food insecurity is an important determinant of multiple forms of malnutrition, as demonstrated through household- and individual-level data drawn from countries in all regions of the globe. In least-developed countries, food insecurity predicts stunting, wasting, and micronutrient deficiencies. In upper-middle- and high-income countries, living in a food-insecure household is a predictor of obesity among school-age children, adolescents, and adults (FAO et al., 2019).

The correlation between the number of severely food insecure, extremely poor, and undernourished people, as well as the rising numbers of undernourished and of people affected by severe food insecurity, demands approaches that jointly work to eradicate poverty, hunger, food insecurity, and malnutrition. Put simply, food security and nutrition concerns must be integrated into efforts to reduce poverty (FAO et al., 2019).

Nutrition constitutes an integral component of food security and therefore occupies a central position in addressing the aforementioned challenges. Without adequate nutrition, food security cannot be achieved. Hence, nutrition warrants important consideration across all four pillars of food security, and therefore cannot be considered a minor or incidental concern in global efforts to eliminate food insecurity and malnutrition and to achieve sustainable development goal (SDG) #2: zero hunger: end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (United Nations, n.d.). Indeed, nutrition is implicated in many of the SDGs.

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In this chapter, definitional issues are initially presented before exploring the indicators of food (in)security and (mal)nutrition. The scope of food insecurity and the triple burden of malnutrition around the globe is also highlighted, including their coexistence and relationship. Finally, the relationship between nutrition and each of the four pillars of food security as well as the importance of integrating nutrition into food security interventions is explored.

1.2 Food security and nutrition: definitions, indicators, and prevalence

1.2.1 Food security: definition, indicators, and prevalence

1.2.1.1 Definition

The 2009 declaration of the World Summit on Food Security defines food security as follows: "Food security exists when all people at all times have physical, social and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (World Summit on Food Security, 2009)[1].

This definition of food security leads to the identification of four pillars or dimensions: availability, access, utilization, and stability (World Summit on Food Security, 2009). Food availability pertains to the supply side of food security and the physical existence of food in a sufficient quantity and of appropriate quality, whether derived from domestic agri-food production, domestic stocks, food imports, food aid, or a combination thereof. Once the food is available, households and individuals must have sufficient access to that food (FAO et al., 2019). Food access—physical, social, and economic—pertains to the demand side of food security and is achieved through adequate income or other resources to secure appropriate food for a nutritious diet (FAO, 2008). Sufficient food supply does not guarantee food security for either households or individuals, because food access is often more problematic than availability, especially for the most malnourished people (World Bank, 2007). Provided that food is available and households have adequate access, then food security requires that households can consume adequate nutrients and energy (FAO et al., 2019). Food utilization refers to the way in which the body extracts and uses the nutrients found in food, and is rooted in nutritious food selection, a diverse diet, sound eating habits, proper food preparation and hygiene practices, and intra-household distribution of food. Finally, stability indicates the consistency of achieving the pillars of availability, access, and utilization over time. Stability concerns both short-term instability that may cause acute food insecurity and medium- to long-term instability that may cause chronic food insecurity. Stability may be adversely impacted by a range of factors including climatic, economic, social, and political factors (FAO et al., 2019). Achieving food security requires that all four pillars be met simultaneously (FAO, 2008).

1.2.1.2 Indicators of food security

It is important to note that food security is a complex issue. Accordingly, there is no single, universally accepted measure of food security (Carletto et al., 2013).[2] Food security cannot be measured directly, and so proxy indicators are

[1] An earlier definition of food security as adopted in 1996 is often cited in the literature, with the difference that it excludes the term "social" access.

[2] There is a rich literature exploring the relative merits of various indicators of food security, and a comprehensive review is beyond the scope of this chapter. A number of academic articles and chapters were produced, particularly in advance of adoption of the SDGs. Readers are referred to Ballard et al. (2014), Cafiero et al. (2014), Carletto et al. (2013), Jones et al. (2013), and Pangaribowo et al. (2013) for recent, detailed reviews of indicators of food and nutrition security.

used (Barrett, 2010). In fact, policymakers and practitioners now acknowledge that, as food security encompasses multiple dimensions, there is a need for a wide range of assessment indicators (Maxwell et al., 2013; Vaitla et al., 2017).[3] Moreover, food security may be measured at the level of the country or region, the household, or the individual. Indicators may be singular or composite. Several leading indicators including those used to track progress against SDG 2 are shown in Table 1.1 of which several are highlighted within the text.

A key indicator of food insecurity is hunger—the uncomfortable or painful sensation caused by insufficient consumption of food energy—measured as the prevalence of undernourishment (PoU). PoU is defined as the proportion of the population that lacks sufficient dietary energy to lead a healthy and active life. PoU is used to track country progress with regard to SDG 2 (FAO et al., 2019).

Another key indicator of food insecurity is the food insecurity experience scale (FIES), which was recently developed as an indicator of the prevalence of moderate and severe food insecurity in order to track SDG Target 2.1—the prevalence of moderate or severe food insecurity. The FIES is composed of a set of eight questions that assess individuals' or households' access to food, such that food insecurity as measured by this indicator reflects limited access to food as a result of a lack of financial or other resources (FAO et al., 2019). The FIES allows for direct measurement of access to food, in contrast to other traditional measures that assess either the determinants or the consequences of food security. The FIES tool has been developed in such a way as to allow valid comparisons across different populations around the globe, as well as to serve as an early warning for action before the long-term and irreversible consequences of food insecurity-related malnutrition that appear within a population (Ballard et al., 2014). Severe food insecurity is closely related to the concept of hunger (measured as PoU), or with individuals or households consuming insufficient food energy. However, while all hungry people are, by definition, food insecure, not all food-insecure people are hungry (FAO, 2008). Moderate food insecurity indicates that individuals or households have an uncertain ability to obtain food, leading to compromises in terms of the quantity or quality of the food they consume; however, these compromises do not result in insufficient consumption of dietary energy (undernourishment) (FAO et al., 2019). Irregular access to sufficient, nutritious food raises the risk of malnutrition and poor health among these people.

Anthropometric measures may be used to measure both food security and nutrition. For example, the prevalence of stunting in a country is sometimes considered as a measure of food security—specifically utilization—as well as a measure of malnutrition (Pangaribowo et al., 2013).

Composite measures of food security have also been structured to reflect the contributors to food (in)security and/or its effects. For example, the global hunger index is a composite measure of three indicators: the PoU and the prevalence of underweight and mortality rates in children under 5 years of age (International Food Policy Research Institute, 2014a). Another composite measure, the global food security index (GFSI), builds on 28 unique indicators that relate to affordability, availability, and quality and safety of food, with an additional adjustment factor related to natural resources and resilience. The GFSI scores countries from 0 to 100 and ranks their relative

[3] For example, De Haen et al. (2011) review leading indicators of food insecurity (prevalence of undernourishment, household food consumption surveys, and childhood anthropometrics) on their merits and limitations and propose to use those in combination given their varying purposes, level of measurement, and timeliness; and call for the development of comprehensive, standardized, and timely household surveys of both food consumption and anthropometry.

TABLE 1.1 Selected measures of food security.

Measure or tool	Level of measurement	Description
Anthropometric measures	Individual	Include measures such as stunting (height-for-age) and wasting (weight-for-age, weight-for-height)
Self-assessed measure of food security (SAFS)	Individual	Include self-assessments of current food security status in recent recall period and changes in livelihood status over long recall period; highly subjective tool
Food insecurity experience scale (FIES)	Individual or household	Reflects limited access to food as a result of a lack of financial or other resources
Dietary diversity score (DDS)	Individual or household	Reflects the number of different foods or food groups consumed over a given reference period (typically 24 hours); captures quality and diversity of food eaten
Food frequency score (FFS)	Individual or household	Number and frequency with which different kinds of food are eaten
Food consumption score (FCS)	Household	A frequency-weighted DDS calculated using the frequency of consumption of different food groups during previous 7 days; a composite score based on dietary diversity, food frequency, and relative nutritional importance of different food groups; captures quantity, quality, and diversity of food eaten
Coping strategy index (CSI) and reduced coping strategy index (rCSI)	Household	Count of the frequency and severity of behaviors in which people engage when they do not have enough food or money to buy food (consumption changes, expenditure reduction, or income expansion); captures element of quantity or sufficiency of food eaten
Household food insecurity and access scale (HFIAS)	Household	Captures both sufficiency and psychological factors related to food
Household hunger scale (HHS)	Household	Developed from the HFIAS and comprised of three culturally invariant questions; a behavioral measure intended to reflect more severe behaviors; captures most extreme manifestations of insufficiency of food
Prevalence of undernourishment (PoU)	Population	Measure of food deprivation, based on a comparison of usual food consumption as expressed in terms of dietary energy intake (kcal); a proxy measure of food energy consumption
Global hunger index (GHI)	Population	Composite measure of three indicators: the proportion of undernourished population and the prevalence of underweight and mortality rate in children under 5 years of age

Authors' original, adapted from Vhurumuku, E., 2014, February. Food security indicators. World Food Programme East and Central Africa Bureau. Presentation to Integrating Nutrition and Food Security Programming for Emergency Response Workshop, Nairobi, Kenya; Maxwell, D., Coates, J., Vaitla, B., 2013. How Do Different Indicators of Household Food Security Compare? Empirical Evidence from Tigray. Feinstein International Center, Tufts University, Medford, MA. Retrieved from <https://www.alnap.org/system/files/content/resource/files/main/different-indicators-of-hfs.pdf>.

TABLE 1.2 Global food security index, best and worst performers—2018.

Best performers			Worst performers		
Rank	Country	Score	Rank	Country	Score
1	Switzerland	85.9	109	Sierra Leone	29.2
2	Ireland	85.5	110	Yemen	28.5
=3	United Kingdom	85.0	111	Madagascar	27.0
=3	United States	85.0	112	Democratic Republic of Congo	26.1
5	Netherlands	84.7	113	Burundi	23.9

Data from Economist Intelligence Unit (EIU), 2019. The global food security index. Retrieved from <https://foodsecurityindex.eiu.com/> (accessed 05.12.19.).

TABLE 1.3 Prevalence (%) of undernourishment, by region and subregion, 2005–18.

Region/subregion	2005 (%)	2010 (%)	2015 (%)	2018 (%)
Africa	21.2	19.1	18.3	19.9
North Africa	6.2	5.0	6.9	7.1
Sub-Saharan Africa	24.3	21.7	20.9	22.8
Asia	17.4	13.6	11.7	11.3
Central Asia	11.1	7.3	5.5	5.7
East Asia	14.1	11.2	8.4	8.3
Southeast Asia	18.5	12.7	9.8	9.2
South Asia	21.5	17.2	15.7	14.7
West Asia	9.4	8.6	11.2	12.4
Latin America and the Caribbean	9.1	6.8	6.2	6.5
Caribbean	23.3	19.8	18.3	18.4
Latin America	8.1	5.9	5.3	5.7
Oceania	5.5	5.2	5.9	6.2
North America and Europe	<2.5	<2.5	<2.5	<2.5
World	14.5	11.8	10.6	10.8

Data from FAO et al., 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. <http://www.fao.org/3/i9553en/i9553en.pdf>. Licence: CC BY-NC-SA 3.0 IGO.

performance, highlighting factors that may need to be targeted by policymakers. Table 1.2 displays the best and worst performers among 113 countries included in the 2018 GFSI (Economist Intelligence Unit, 2019). The worst performing countries on the GFSI are, perhaps unsurprisingly, among the poorest countries in the world and with a recent history of conflict. Pangaribowo et al. (2013) provide a useful review of these and other composite indices and their relation to the pillars of availability, access, utilization, and stability.

1.2.1.3 Prevalence of food security

Despite significant progress in the global fight against food insecurity, millions of individuals continue to suffer from hunger and malnutrition.[4]

As of 2019, approximately 821 million people or 11% of the global population were hungry (measured as PoU) (Table 1.3). Regions in which hunger remains most problematic and has even increased in recent years include sub-Saharan Africa, where the rate of hunger now stands at 22.8% as compared to 20.9% in 2015. Similar increases have also been observed in recent years in Latin America and the Caribbean (6.5% in 2018 vs 6.2% in 2015) and West Asia (12.4% in 2018 vs 11.2% in 2015). South Asia has also reported a relatively high prevalence of hunger, remaining nearly 15% in 2018. In absolute numbers, the population of those suffering from hunger (undernourished) lived primarily in Asia

[4] While a large body of research provides evidence that food security and improved health are generally and positively correlated with economic growth and prosperity (Pangaribowo et al., 2013; Thomas and Frankenberg, 2002), the recent global performance highlights that economic growth will not automatically solve these problems as previously speculated (HLPE, 2017).

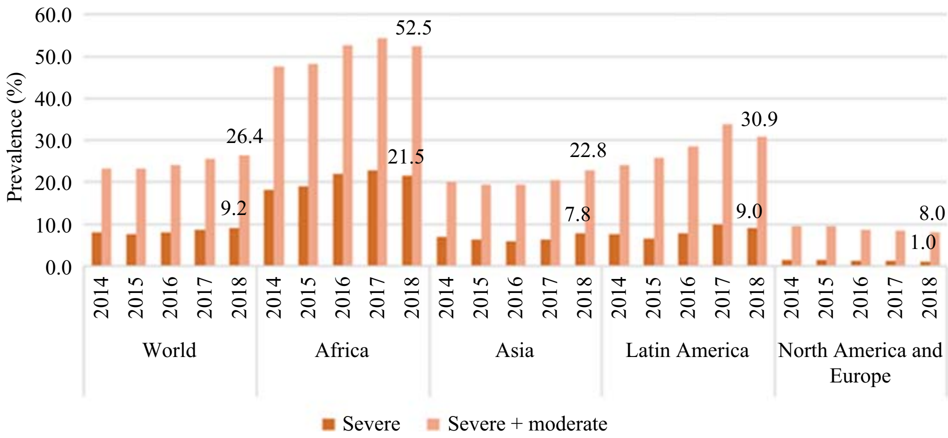

FIGURE 1.1 Prevalence (%) of moderate and severe food insecurity, by region, 2014–18.[5] Source: *Data from FAO et al., 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. Licence: CC BY-NC-SA 3.0 IGO.*

(514 million) and in Africa (256 million) as of 2018. The lowest rate of hunger has been reported in North America and Europe since 2005 (<2.5%) (FAO et al., 2019).

Approximately two billion people globally or 26.4% of the global population experienced moderate or severe food insecurity in 2019, as measured using the FIES. Of these, approximately 1.3 billion or two-thirds suffer from moderate food insecurity and the remaining people suffer from severe food insecurity. The problem of food insecurity has worsened in recent years (2014–18) and is concentrated in low- and middle-income countries, with the highest levels reported in Africa (52.5%), Latin America (30.9%), and Asia (22.8%). Even high-income countries in Europe and North America report moderate or severe food insecurity (albeit to a lesser extent, at 8.0%). Fig. 1.1 shows the increased prevalence of moderate and severe food insecurity over time, globally and across most regions. The prevalence of moderate and severe food insecurity is higher among women than men, both globally and across every geographic region of the world (FAO et al., 2019). This gender disparity is attributable to several factors and forms of discrimination that reduce women's access to food, such as differences in household income, poverty status, educational achievement, area of residence, and social networks (Quisumbing et al., 1995; Headey, 2013).

1.2.2 Malnutrition: definition, indicators, and prevalence

1.2.2.1 Definition

According to FAO et al. (2019), "Malnutrition is an abnormal physiological condition caused by inadequate, unbalanced or excessive consumption of macronutrients and/or micronutrients. Malnutrition includes undernutrition (child stunting and wasting and vitamin and mineral deficiencies) as well as overweight and obesity" (188). Moreover, "Malnutrition may be an outcome of food insecurity, or it may relate to *non-food* factors, such as inadequate care practices for children, insufficient health services, and an unhealthy environment" (FAO, 2008: 3). Biology, epigenetics, early-life nutrition, diets (Box 1.1), socioeconomic factors, food environments and systems, and governance have all been identified as drivers of the different forms of malnutrition (Hawkes et al., 2020).

[5] Region-level results are not reported for Oceania.

BOX 1.1

Dietary diversity

An important concept that is related to malnutrition and that deserves specific mention is dietary diversity. Dietary diversity is key for both ensuring adequate nutrition and preventing malnutrition, because a larger variety of foods in the diet "is thought to ensure adequate intake of essential nutrients and to promote good health" (Ruel, 2003: 3911S). For example, diets that feature a combination of starchy stables, vitamin A-rich fruits and vegetables, and animal-source foods are linked to a reduced risk of stunting (Hawkes et al., 2020). Conversely, a lack of sufficiently diverse dietary intake can lead to adverse health outcomes, namely micronutrient deficiencies (Shetty, 2009; Hawkes et al., 2020), even among individuals who consume sufficient dietary energy and so are not undernourished or hungry.[6] This is particularly true for vulnerable population groups, such as young children, adolescent girls, and women.[7] A recent meta-review found, however, no significant association between dietary diversity and overweight, obesity, or mean body mass index (BMI) (Salehi-Abargouei et al., 2016).

1.2.2.2 *Indicators and prevalence of malnutrition*

Concomitant with the definition presented earlier, indicators of malnutrition may reflect deficiencies, excesses, or imbalances in the intake of macro- and micronutrients. Some measures of nutrition refer to food consumption, with an emphasis either on calories consumed (for example, the PoU, stunting, and wasting) or the quality of the diet consumed (for example, the prevalence of overweight and obesity).

Stunting and wasting are the two outcome indicators of deficiencies in macronutrient intake, specifically calorie consumption, as well as other factors including maternal care, sanitation, and access to health and social services (Ballard et al., 2014). Stunting, or low height-for-age, reflects one or more past episodes of sustained undernutrition. Wasting, or low weight-for-height, generally results from weight loss associated with a recent period of inadequate dietary energy intake and/or disease. In children less than 5 years of age, stunting and wasting are defined as height-for-age and weight-for-height less than −2 standard deviations below the respective World Health Organization (WHO) Child Growth Standards medians (WHO, 2006a). The prevalence of stunting and wasting is reported at the national or population level.

The global prevalence of stunting among children under 5 years of age was 21.9% in

[6] In an extreme case, a young man had an extremely restricted diet of French fries (chips), potato chips, white bread, and processed meat products (ham, sausage) consumed over a period of years. This consumption pattern allowed him to maintain a normal Body Mass Index (BMI) but led to severe deficiency of vitamin B12 and vitamin D, inter alia, and eventually loss of vision and hearing (Harrison et al., 2019).

[7] Various studies have explored dietary diversity and its impacts on vulnerable populations. For more on dietary diversity among young children, readers are referred to WHO (2002), Dewey (2013), WHO (2010), and IFPRI (2014b); among adolescents, to Ochola and Masibo (2014) and Elliot et al. (2015); and among women of reproductive age, to Arimond et al. (2010) and Kothari et al. (2014).

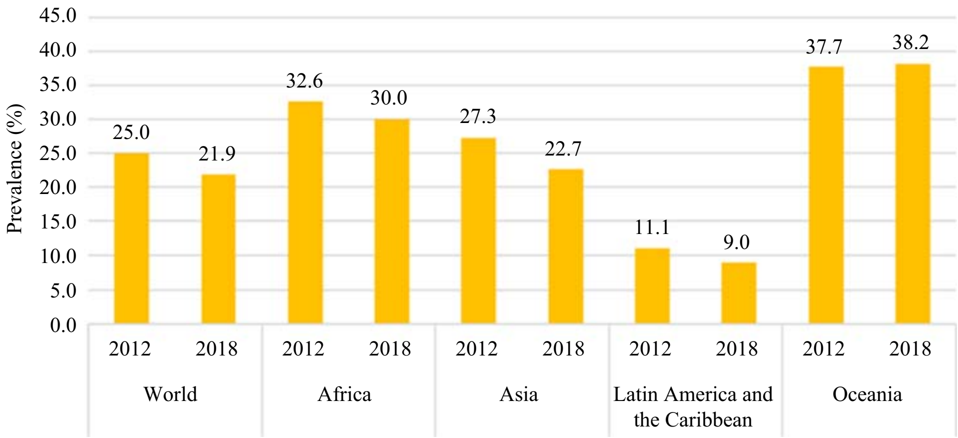

FIGURE 1.2 Prevalence (%) of stunting in children under 5 years of age, by region, 2012–18. Source: *Data from FAO et al., 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. Licence: CC BY-NC-SA 3.0 IGO.*

2018, or approximately 148.9 million children (Fig. 1.2). The majority of stunted children under the age of 5 lives in Africa, comprising 39.5% of the total, and in Asia, comprising 54.9% of the total. In terms of prevalence rates in 2018, the highest rates of stunting among children were reported in Oceania, where 38.2% of all children under 5 years of age were stunted (FAO et al., 2019).

Approximately 49.5 million children, or 7.3% of all children, were wasted as of 2018. This figure falls short of global targets to reduce wasting to less than 5% by 2025. Geographically, the highest prevalence rates of wasting were reported in Asia and Oceania, where 9.4% of all children under 5 years of age were wasted (FAO et al., 2019).

Overweight and obesity are the outcomes of an imbalance between energy intake and expenditure. Both overweight and obesity are measured by the ratio of weight to height (kg/m^2), known as BMI, according to age groups (children under 5 years of age, adolescents 5–19, and adults). In children below 5 years of age and adolescents, a BMI-for-age greater than one standard deviation above the WHO growth reference standard median is defined as being overweight, whereas a BMI-for-age greater than two standard deviations above the median is considered obese. Adults ($\geq$18 years old) with BMI $\geq 25\,kg/m^2$ and BMI $\geq 30\,kg/m^2$ are considered overweight and obese, respectively (FAO et al., 2019). Countries periodically report and monitor the prevalence of overweight and obesity in their populations.

By 2016, the total number of obese people (approximately 822 million) exceeded the total number of undernourished people (796.5 million) globally. When evaluated by age, the lowest rate of overweight was reported among children under 5 years of age (5.9% globally, with regional rates ranging from 4.9% in Africa to 9.1% in North America, whereas the highest prevalence was reported for adults 18+ at 38.9% globally, with regional rates ranging from 29.8% in Africa to 67.5% in North America). Fig. 1.3 shows the prevalence of overweight, globally and by regions, across age groups in 2016. In terms of prevalence rates, the highest rates of overweight among children were reported in Oceania, where 9.1% of all children under 5 years of age were overweight. Among older age groups, over half of adults

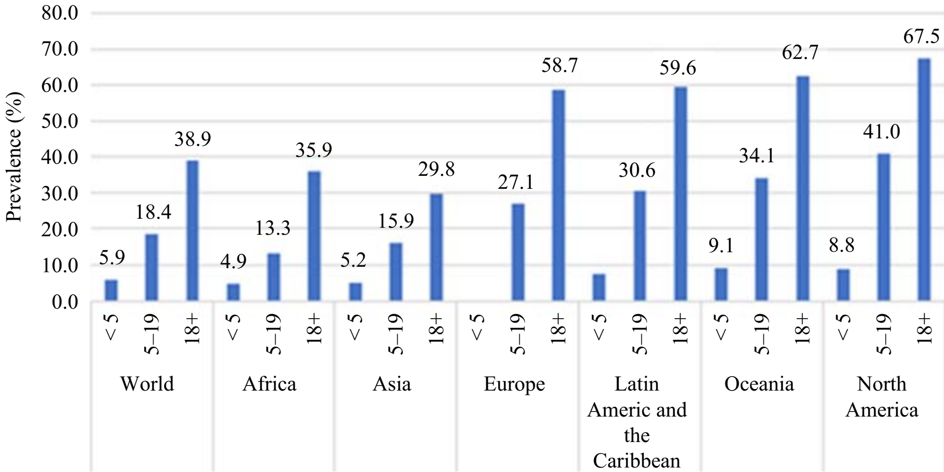

FIGURE 1.3 Prevalence (%) of overweight, by region and by age, 2016. Source: *Data from FAO et al., 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. Licence: CC BY-NC-SA 3.0 IGO.*

(58.7%–67.5%) and more than one-quarter of school-age children (27.1%–41%) in North America, Oceania, Latin America, and Europe were overweight.

The prevalence of overweight and obesity continues to rise, both globally and in all regions and across all age groups. All regions, with no exception, have experienced a remarkable increase of approximately 10 percentage points in the prevalence of overweight among adults between 2000 and 2016. Increases in the prevalence of obesity were greater than increases in overweight between 2000 and 2016 (FAO et al., 2019). Among school-age children, the rising rate of overweight is already high and accelerating in Asia (6.7% in 2000 to 16% in 2016) (NCD-RisC, 2017). The rising incidence of overweight among school-aged children is associated with poor food consumption patterns (insufficient fruit and vegetable intake, excessive consumption of fast food and soft drinks) as well as physical inactivity (WHO, 2019).

Deficiency or imbalance in micronutrient intake is frequently reported with regard to several key micronutrients, or in terms of the health outcome associated with that deficiency. The prevalence of micronutrient deficiency—sometimes termed "hidden hunger"—is reported at the national or population level, though reporting may be specific to vulnerable population groups. The micronutrient deficiencies of greatest concern for public health are vitamin A, iron, and iodine, particularly among children under 5 years of age, pregnant women, and women of reproductive age. Vitamin A deficiency causes blindness in children and raises the risk of disease and death from infection. Iron-deficiency anemia particularly affects women, reducing their mental capacity and work productivity. Iodine deficiency during pregnancy may impair a child's mental health and even cause death (HLPE, 2017).

In terms of prevalence, micronutrient deficiencies remain problematic among certain vulnerable populations. For example, in 2016, 32.8% of women of reproductive (age 15–49) were affected by anemia, indicating an increase of 8% from 2012. Rates of anemia were highest among women of reproductive age in Africa and Asia, with rates more than twice those reported in North America and Europe (FAO et al., 2019).

Growing evidence points to the coexistence of multiple forms of malnutrition in a given population. For example, the term triple burden of malnutrition refers to the coexistence of undernutrition, micronutrient deficiencies, and overweight or obesity (Johnston et al., 2014) within a country, region, or household. For example, a stunted child and overweight or obese mother may live within the same household (Ghattas, 2014; Maitra, 2018). At the individual level, an overweight or obese woman could also suffer anemia, and a child could be simultaneously stunted and overweight (Ghattas, 2014; Maitra, 2018). The double burden of malnutrition refers to the simultaneous occurrence of undernutrition and overweight and obesity (Popkin et al., 2020). The latest available evidence finds that among 126 lower-middle-income countries studied, 48 countries or 38% face a double burden of malnutrition. A high prevalence of the double burden of malnutrition was observed especially in sub-Saharan Africa, South Asia, East Asia, and the Pacific (Popkin et al., 2020).[8]

1.2.3 The burden of global food insecurity and malnutrition

The effects of food insecurity and malnutrition are important and reach well beyond the individual level. These effects can take several forms, notably social and economic.

Food insecurity strongly predicts higher health care use and costs, including emergency department visits, inpatient admissions, and length of stay (Berkowitz et al., 2018a). In 2014 hunger and food insecurity accounted for $160 billion of the estimated health-related costs in the United States, more than all annual state and federal spending on higher education (Cook and Poblacion, 2016). Between 2011 and 2013, people experiencing food insecurity faced an additional $1863 per person in annual health care costs, compared to their food-secure counterparts, which summed to $77.5 billion in excess annual health care expenditures (Berkowitz et al., 2018b). Health care costs were found to be significantly more pronounced among food-insecure adults with hypertension, stroke, arthritis, and diabetes (Garcia et al., 2018). In fact, food insecurity is associated with poor control of chronic diseases including diabetes and with risk factors including obesity and smoking (Castillo et al., 2012; Fitzgerald et al., 2011; Pan et al., 2012; Parker et al., 2010). Food insecurity is also linked to a range of other chronic diseases, health conditions, and health behaviors across all age groups (FRAC, 2017).

While food insecurity affects the physical and mental health of all age groups, it appears to be specifically harmful to the health, development, and well-being of children over the short and long term (Nord and Parker, 2010; American Academy of Pediatrics, 2015; Gundersen and Ziliak, 2015; Shankar et al., 2017). Children who live in food-insecure households have a higher risk of illness, are hospitalized more frequently, and recover from their illness more slowly than children who live in food-secure households. Insufficient consumption of adequate and nutritious food can limit a child's ability to concentrate or perform well in school and is associated with behavioral and emotional problems throughout childhood and adolescence (Food Research and Action Center FRAC, 2017: 3).

Moreover, food-insecure older adults were found to resort to underuse of cost-related medication, defined as reducing, delaying, skipping, or using cheaper medications to offset a lack of household resources to buy food (Berkowitz et al., 2014; Soumerai et al., 2006). Increased severity of food insecurity increased

[8] The authors focus on the double burden of malnutrition in their study due to insufficient data to include micronutrient deficiencies and therefore the triple burden of malnutrition.

the likelihood of engaging in such behaviors (Herman et al., 2015).

The impacts of food insecurity and malnutrition are also shown to affect societies, insofar as they may be linked to armed conflict. For example, research has found that poor health and nutritional status may serve to induce armed conflicts in poor countries, notably in the form of food riots as observed in many areas of the globe in 2008 (Pinstrup-Andersen and Shimokawa, 2008: 513).

Malnutrition similarly imposes a high cost on society and communities, in terms of human lives. Indeed, "Malnutrition associated with diets that are not nutritious or safe represents the number one risk factor in the global burden of disease" (GLOPAN, 2016: 16). The latest evidence is that 22% or one in five adult deaths globally is attributable to a suboptimal diet (GBD 2017 Diet Collaborators, 2019). Impacts can also be significant, particularly among vulnerable populations: Approximately 45% of all deaths among children under 5 years of age in low- and middle-income countries are estimated to be a result of maternal and child undernutrition (Black et al., 2013). Among all forms of malnutrition, overweight and obesity alone contribute to the deaths of approximately four million people a year (FAO et al., 2019). An estimated one-third of the global population does not meet its physical or economic potential as a result of micronutrient deficiencies (Shetty, 2009).

Malnutrition also poses a heavy burden in terms of the economic costs paid by individuals and governments. The economic costs of malnutrition are high and rising costs (FAO et al., 2019). Stunted children face permanent disadvantages linked to worse academic performance and lower economic earnings (Global Panel on Agriculture and Food Systems for Nutrition GLOPAN, 2016). Undernutrition is estimated to reduce the gross domestic product of African and Asian countries by 11%, whereas obesity imposes global costs of some $20 trillion each year in terms of lost productivity and direct health care costs (FAO et al., 2019). Conversely, the return on investment in nutrition is high and positive, serving as a boost to economic growth (Global Panel on Agriculture and Food Systems for Nutrition GLOPAN, 2016).

1.3 Food insecurity and malnutrition coexist: correlations and causalities

1.3.1 The conceptual link between food security and nutrition

Nutrition is a central element of food security. The definition of food security requires that food be nutritious and meet dietary needs. Without adequate nutritious food, food security cannot be achieved, either by individuals or communities. Indeed, the World Summit on Food Security stated in 2009, "The nutritional dimension is integral to the concept of food security" (World Summit on Food Security, 2009: 1). For this reason, food security is sometimes termed "food and nutrition security" and abbreviated as FNS, merging the concepts to emphasize both food and health requirements for a more complete definition (Pangaribowo et al., 2013).[9] Nevertheless, we use the simplified term food security throughout this chapter. If food security is a determinant factor of

[9] Elsewhere, the Rome institutions have defined nutrition security as "a situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, in order to ensure a healthy and active life for all household members. Nutrition security differs from food security in that it also considers the aspects of adequate caring practices, health and hygiene in addition to dietary adequacy" (FAO et al., 2012: 57). This definition of nutrition security effectively incorporates the concept of food security, building on and expanding it; according to this definition, nutrition security cannot be achieved without food security.

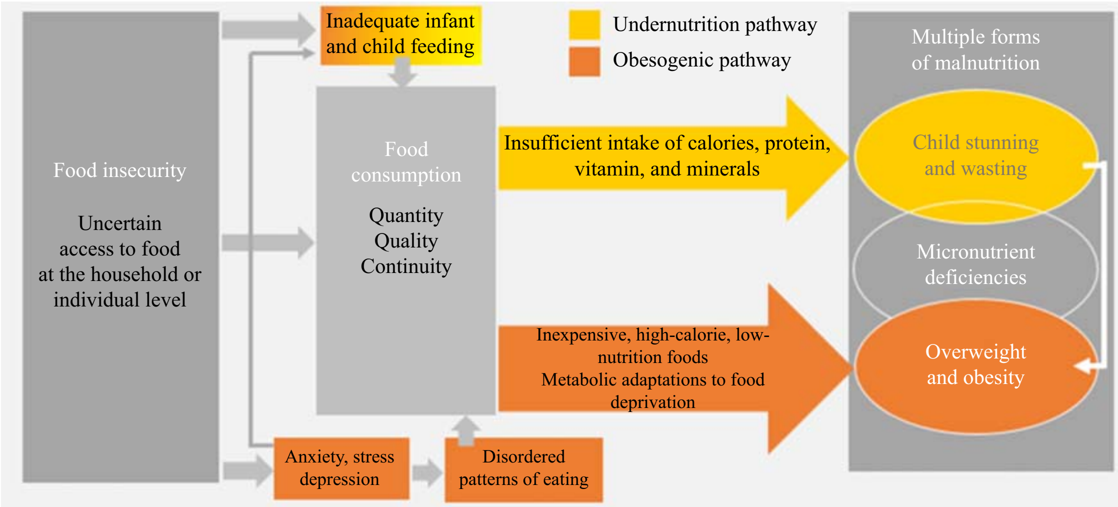

FIGURE 1.4 Pathways from inadequate food access to multiple forms of malnutrition. Reproduced with permission from*: FAO et al., 2018. The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition. FAO, Rome. <http://www.fao.org/3/i9553en/i9553en.pdf>. Licence: CC BY-NC-SA 3.0 IGO. Reproduced with permission.*

nutritional status, it is only one of several factors (Maxwell et al., 2013).

The relationship between food security and nutritional outcomes may be complex, but it is not in doubt. "Analysis of household and individual-level data from selected countries across all regions shows that food insecurity plays an important role as a determinant of many different forms of malnutrition" (FAO et al., 2019: xv). Moreover, food consumption or diet, in terms of quantity, quality and continuity, appears to be the main pathway from food insecurity to malnutrition (FAO et al., 2018). Fig. 1.4 presents an illustration of the various pathways from food insecurity—specifically inadequate food access—to the multiple forms of malnutrition: Uncertain food access may affect food consumption, whereby food consumption in terms of its quality, quantity, and continuity can lead to undernutrition outcomes, overweight and obesity, and micronutrient deficiencies through two principal pathways.

We briefly present the available evidence on correlations and causal relationships between food insecurity—mainly poor access to food at the household or individual level—and various forms of malnutrition in the following sections.

1.3.2 Food insecurity correlates with undernutrition

Food insecurity can directly contribute to child stunting and wasting, as well as micronutrient deficiencies, through inadequate food consumption. Insufficient energy, protein, and micronutrient intake hinders fetal, infant, and child growth and development. Among women of child-bearing age, compromised diets may lead to maternal undernutrition and a higher risk of low birth weight, both of which are contributors to child stunting (FAO et al., 2018). In fact, several studies have demonstrated a strong association between food insecurity and undesirable outcomes on child stunting in Africa, Asia, and Latin America.[10] Of note, evidence on the causal link between food insecurity and child wasting is limited, with very few studies reporting a positive association, particularly in low and lower-middle-income countries (Maitra, 2018). This is because wasting is an indicator of acute malnutrition and may be the result of other factors, such as recurrent infections and diseases, as well as acute shocks and humanitarian crises (FAO et al., 2018). Concerning micronutrient deficiencies, food insecurity has been shown to be a risk factor for anemia in women of reproductive age, as demonstrated by several studies from diverse countries (Maitra, 2018).

The stress of living with food insecurity can also lead to undernutrition through its impact on infant and child feeding. Infants in food-insecure households face a lower likelihood of being exclusively breastfed, and, therefore, at a higher risk for stunted and wasted growth given the inverse relationship between exclusive breastfeeding during the first 6 months and these nutritional outcomes. In addition, in lower-middle-income and high-income countries, mothers living in food-insecure households are reported to face higher rates of maternal depression and stress, which can weaken their confidence and self-efficacy and negatively influence breastfeeding as well as complementary feeding practices (Maitra, 2018).

1.3.3 Food insecurity correlates with overweight and obesity

Available evidence indicates a significant relationship between food insecurity and overweight and obesity. For example, national-level evidence points to a positive correlation between food insecurity (measured using the FIES) and overweight and obesity: according to the analysis of Del Grossi et al., "Countries with higher prevalence of moderate or severe food insecurity based on the FIES tend to have higher rates of adult obesity, when controlling for national rates of undernourishment and poverty" (FAO et al., 2019: 42). Household-level evidence also reveals important correlations. In upper-middle- and high-income countries, living in a food-insecure household is associated with higher rates of obesity among school-age children, adolescents, and adults. However, this result does not hold in low- and lower-middle-income countries, where living in a food-insecure household is associated with lower risk of overweight and obesity, or is not associated at all (FAO et al., 2019). Moreover, the relationship between food insecurity and overweight and obesity may reveal itself later in life: for example, children who experience hunger and food insecurity may have a greater likelihood of being overweight or obese and of suffering from noncommunicable diseases later in life (FAO et al., 2019).

What are the causal relationships underpinning these correlations? Food security has been identified as a key determinant of long-term energy balance, which in turn is a determinant of overweight. Additional factors that may serve to explain the connection between food insecurity and overweight and obesity are the fact that nutritious foods are more expensive, leading to their substitution with cheaper foods containing more fats and sugars; the stress that results from having uncertain access to food; and physiological changes that result from periodic restrictions in food consumption (FAO et al., 2019).

Research has found that "As national economies grow, people facing difficulties in accessing food, as captured by an experience-based indicator of food insecurity, have a higher risk

[10] Stronger evidence of this association depends on more timely reporting of child stunting data: stunting data are typically much older than available FIES data, which tends to obscure the association between food insecurity and child stunting (FAO et al., 2018).

of obesity" (FAO et al., 2019: 43). Within high-income countries, low-income households and individuals often experience food insecurity as low-quality diets marked by the consumption of foods high in calories, fat, sugar, and salt. These diets may result in excessive food energy consumption; deficiencies in protein and micronutrients including iron, folate, calcium, and selected vitamins; and diet-related non-communicable diseases (Hawkes et al., 2020). In upper-middle- and high-income countries, such highly processed and energy-dense foods are typically widely available and less expensive than fresh, nutritious foods (FAO et al., 2019). Similarly, in low- and middle-income countries, the association of food insecurity with obesity is determined by the affordability of highly processed, energy-dense foods and spatial-temporal access to nutritious food (inter alia) (Farrell et al., 2018). To avoid hunger and maximize their food budgets, low-income families and food-insecure households substitute lower-cost, energy-dense but nutrient-depleted foods for more nutrient-dense ones (Darmon et al., 2002; Radimer et al., 1992). Malnutrition may result from inconsistent and inadequate diets, for example, if individuals overconsume food when it is available or accessible, contributing to overweight and obesity (Polivy, 1996; Townsend et al., 2001).

On the psychosocial front, uncertain or inadequate access to food may result in feelings of anxiety, stress, and deprivation. These feelings may then lead to behaviors that increase the risk of overweight and obesity, such as binging or overeating when food is available and choosing cheap, high-calorie "comfort foods" that are high in fat, salt, and sugar, and that have been found to reduce stress over the short term (FAO et al., 2018). Among women, the stress of living with food insecurity can negatively affect the initiation and duration of breastfeeding and young child feeding practices, which consequently raise the risk of adult-onset obesity (Maitra, 2018).

In terms of physiological adaptation, evidence points to a relationship between food insecurity during childhood and a higher risk of overweight both during childhood as well as later in life. Children who are stunted have shown a higher risk of being simultaneously overweight (FAO et al., 2018). Moreover, food insecurity is associated with low birth weight in infants, a risk factor for child stunting, which, in turn, is associated with adulthood overweight and obesity (Maitra, 2018) among children who later adopt energy-dense diets and sedentary lifestyles (WHO, 2016). In addition, maternal nutrition can play a role, setting in motion an intergenerational cycle of malnutrition: a mother's lack of stable access to an adequate diet can cause undernutrition and/or overweight in her, as well as program metabolic, physiological, and neuroendocrine functions in her children (FAO et al., 2018 citing Levin, 2006 and Pérez-Escamilla et al., 2018).

Evidence on the correlation of food insecurity and overweight and obesity has been reported in both resource-poor and resource-rich settings. In high-income countries, a positive association between food insecurity and obesity has been well established among women. In the United States, the prevalence of obesity was shown to be significantly higher among food-insecure adults than among food-secure adults (35.1% vs 25.2%) (Pan et al., 2012). In Lebanon, an upper-middle-income country in the Middle East, mothers from food-insecure households were shown to have a significantly higher risk of obesity than food-secure ones. Food-insecure mothers reported consuming significantly less nutrient-dense foods, such as dairy products, fruits, and nuts, but more bread and sweets. Food-insecure mothers were less likely to consume the recommended levels of key micronutrients such as potassium, folate, and vitamin C than their food-secure counterparts (Jomaa et al., 2017).

1.3.4 Food insecurity correlates with multiple forms of malnutrition

According to an analysis of microlevel data from eight countries by Ishaq et al., living in a food-insecure household (based on the FIES or a similar experience-based tool) was associated with multiple forms of malnutrition in different population groups in five of the eight countries studied. Forms of malnutrition studied included stunting and wasting (among children), overweight, obesity, and anemia (in women of reproductive age) (FAO et al., 2019).

Using national-level data, we similarly find an elevated prevalence of food insecurity and multiple forms of malnutrition coexisting in many countries: A total of 75 countries reflect a simultaneous presence of food insecurity (measured via FIES) and/or multiple forms of malnutrition, according to the latest available data (Table 1.4). Cells highlighted in gray indicate food insecurity or malnutrition levels above the indicated threshold.[11] Of these, 24 countries report elevated levels of food insecurity and at least one form of malnutrition. Of these countries, a majority are found in sub-Saharan Africa (18 of 24), with the remaining located in Asia (3) and in Latin America (3). For example, Niger suffers from elevated levels of food insecurity, wasting and stunting among children under 5 years of age, and anemia among women of reproductive age. Notably, data on the food security status are unavailable for 40 of these 75 countries; it seems probable that a number of these countries would have elevated rates of food insecurity if data were available. An alternative presentation is shown in Fig. 1.5, which clearly displays the clustering of food security and/or multiple forms of malnutrition. Notable are the coincidences of elevated rates of both food insecurity and child stunting, of child stunting and anemia in women, of child stunting and child wasting, and of child overweight and adult obesity.

1.4 Integrating nutrition in all pillars of food security

From the previous discussion, it is evident that nutrition represents an integral component of food insecurity. In the following section, we explore the integration of nutrition within each of the four pillars of food security, including examples of how nutrition considerations can be featured within interventions to improve food security.

1.4.1 Availability: nutrition and agri-food production

Food availability—or the lack thereof—establishes the most fundamental level of the food environment that determines dietary choices in terms of quantity and quality. Current global food availability makes it theoretically possible for all individuals to consume sufficient calories; however, consumption of nutritious diets by all people is not possible (Herforth and Ahmed, 2015). Many countries emphasize the quantities of food produced and the commercial value of crops, rather than their nutritional qualities. Agricultural breeding tends to focus on traits including yield and appearance over nutritional composition. At the level of the farmer, production decisions and the choice of crop or cultivar are a function of prices, yields, and market preferences, with poor alignment with consumers' dietary needs (Halimi et al., 2019). As a result, important gaps between agricultural production and populations' nutritional needs are reported for nutrient-dense foods including fruits,

[11] Thresholds are based on FAO et al. (2018); excepting the threshold for combined moderate and severe food insecurity, which was set at 40% according to the decision of the authors.

TABLE 1.4 Countries affected by food insecurity and malnutrition.

	Prevalence					
Region/country	**Moderate or severe food insecurity**	**Wasting: children under 5**	**Stunting: children under 5**	**Overweight: children under 5**	**Obesity: adult**	**Anemia: women of reproductive age**
Prevalence threshold	**≥40%**	**≥10%**	**≥20%**	**≥10%**	**≥20%**	**≥40%**
Afghanistan	54.3	9.5	40.9	5.4	4.5	42.0
Albania	38.6	1.6	11.3	16.4	22.3	25.3
Algeria	*N/A*	4.1	11.7	12.4	26.6	35.7
Angola	64.6	4.9	37.6	3.4	6.8	47.7
Armenia	34.3	4.5	9.4	13.7	20.9	29.4
Bahrain	*N/A*	*N/A*	*N/A*	*N/A*	28.7	42.0
Bangladesh	30.5	14.4	36.2	1.6	3.4	39.9
Barbados	*N/A*	*N/A*	7.7	12.2	24.8	21.6
Benin	*N/A*	5.0	32.2	1.9	8.2	46.9
Botswana	70.0	7.2	31.4	11.2	16.1	30.2
Bulgaria	11.8	3.2	8.8	13.6	27.4	26.4
Burkina Faso	40.7	8.6	21.1	1.7	4.5	49.6
Cambodia	44.9	9.8	32.4	2.2	3.5	46.8
Cameroon	71.2	5.2	31.7	6.7	9.5	41.4
Central African Republic	*N/A*	7.4	39.6	1.9	6.3	46.0
Chad	*N/A*	13.3	39.8	2.8	4.8	47.7
Comoros	*N/A*	31.1	32.1	10.6	6.9	29.3
Congo	*N/A*	8.2	21.2	5.9	8.4	51.9
Cote d’Ivoire	*N/A*	6.1	21.6	1.5	9.0	52.9
Djibouti	*N/A*	21.5	33.5	8.1	12.2	32.7
Democratic Republic of Congo	*N/A*	8.1	42.7	4.4	5.6	41.0
Egypt	36.0	9.5	22.3	15.7	31.1	28.5
El Salvador	40.0	2.1	13.6	6.4	22.7	22.7
Equatorial Guinea	*N/A*	3.1	26.2	9.7	7.4	43.7
Eritrea	*N/A*	15.3	50.3	2.0	4.1	38.1

(*Continued*)

TABLE 1.4 (Continued)

Region/country	Prevalence					
	Moderate or severe food insecurity	**Wasting: children under 5**	**Stunting: children under 5**	**Overweight: children under 5**	**Obesity: adult**	**Anemia: women of reproductive age**
Prevalence threshold	**≥40%**	**≥10%**	**≥20%**	**≥10%**	**≥20%**	**≥40%**
Eswatini	63.5	2.0	25.5	9.0	13.5	27.2
Ethiopia	*N/A*	10.0	38.4	2.9	3.6	23.4
Gambia	54.1	11.0	24.6	3.2	8.7	27.5
Georgia	34.5	1.6	11.3	19.9	23.3	27.5
Ghana	49.6	4.7	18.8	2.6	9.7	46.4
Guatemala	43.6	0.8	46.7	4.9	18.8	16.4
Guinea	74.1	8.1	32.4	4.0	6.6	50.6
Guinea-Bissau	*N/A*	6.0	27.6	2.3	8.2	43.8
Haiti	*N/A*	3.7	21.9	3.4	20.5	46.2
Honduras	49.3	1.4	22.6	5.2	19.4	17.8
India	*N/A*	20.8	37.9	2.4	3.8	51.4
Indonesia	8.1	13.5	36.4	11.5	6.9	28.8
Iraq	*N/A*	7.4	22.1	11.4	27.4	29.1
Kenya	56.5	4.2	26.2	4.1	6.0	27.2
Lebanon	*N/A*	6.6	16.5	16.7	31.3	31.2
Lesotho	77.8	2.8	33.4	7.5	13.5	27.4
Liberia	86.2	5.6	32.1	3.2	8.6	34.7
Libya	*N/A*	6.5	21.0	22.4	31.8	32.5
Malawi	81.9	2.8	37.4	4.6	4.7	34.4
Malaysia	*N/A*	11.5	20.7	6.0	15.3	24.9
Maldives	*N/A*	10.2	18.6	6.1	7.9	42.6
Mali	*N/A*	13.5	30.4	1.9	7.1	51.3
Marshall Islands	*N/A*	3.5	34.8	4.1	52.4	26.6
Mauritania	*N/A*	14.8	27.9	1.3	11.3	37.2
Montenegro	12.0	2.8	9.4	22.3	24.9	25.2
Morocco	*N/A*	2.3	14.9	10.8	25.6	36.9
Mozambique	68.6	6.1	42.9	7.8	6.0	51.0

(*Continued*)

TABLE 1.4 (Continued)

Region/country	Prevalence					
	Moderate or severe food insecurity	Wasting: children under 5	Stunting: children under 5	Overweight: children under 5	Obesity: adult	Anemia: women of reproductive age
Prevalence threshold	**≥40%**	**≥10%**	**≥20%**	**≥10%**	**≥20%**	**≥40%**
Myanmar	*N/A*	6.6	29.4	1.5	5.7	46.3
Namibia	67.9	7.1	22.7	4.0	15.0	23.2
Niger	83.0	10.1	40.6	1.1	4.7	49.5
Nigeria	36.4	10.8	43.6	1.5	7.8	49.8
North Macedonia	13.2	1.8	4.9	12.4	23.9	23.3
Pakistan	*N/A*	7.1	37.6	2.5	7.8	52.1
Papua New Guinea	*N/A*	14.3	49.5	13.7	19.4	36.6
Philippines	52.5	7.1	33.4	3.9	6.0	15.7
Saudi Arabia	*N/A*	*N/A*	9.3	6.1	35.0	42.9
Serbia	11.7	3.9	6.0	13.9	23.5	27.2
Sierra Leone	90.8	9.5	37.8	8.8	7.5	48.0
Solomon Islands	*N/A*	8.5	31.6	4.5	20.5	38.9
Somalia	*N/A*	*N/A*	25.3	3.0	6.9	44.4
South Africa	51.1	2.5	27.4	13.3	27.0	25.8
Sudan	*N/A*	16.8	38.2	3.0	7.4	30.7
Syria	*N/A*	11.5	27.6	17.9	25.8	33.6
Timor-Leste	*N/A*	10.5	50.9	1.4	2.9	41.3
Togo	68.1	6.6	27.6	2.0	7.1	48.9
Tonga	*N/A*	5.2	8.1	17.3	45.9	21.3
Tunisia	*N/A*	2.8	10.1	14.2	27.3	31.2
Turkey	*N/A*	1.9	9.9	11.1	32.2	30.9
Vanuatu	*N/A*	4.4	28.5	4.6	23.5	24.0
Yemen	*N/A*	16.4	46.4	2.5	14.1	69.6

Authors' original, using data from FAO et al., 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. <http://www.fao.org/3/i9553en/i9553en.pdf>. Licence: CC BY-NC-SA 3.0 IGO; FAO et al., 2018. The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition. FAO, Rome. Licence: CC BY-NC-SA 3.0 IGO; Popkin, B.M., Corvalan, C., Grummer-Strawn, L.M., 2020. Dynamics of the double burden of malnutrition and the changing nutrition reality. Lancet. doi: https://doi.org/10.1016/s0140-6736(19)32497-3.

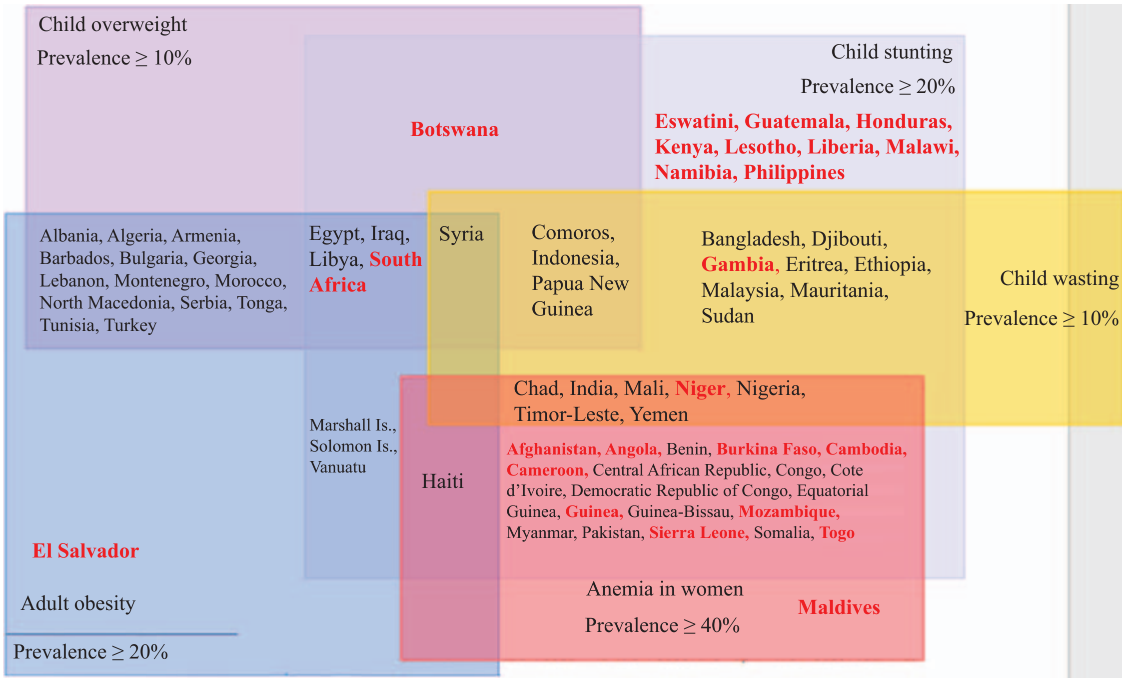

FIGURE 1.5 Countries affected by food insecurity and malnutrition.
Countries highlighted in bold/red additionally report a prevalence of moderate or severe food insecurity greater than or equal to 40%. Source: *Authors' adaptation of FAO et al., 2019, based on data from: FAO et al., 2019. The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns. FAO, Rome. <http://www.fao.org/3/i9553en/i9553en.pdf>. Licence: CC BY-NC-SA 3.0 IGO; FAO et al., 2018. The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition. FAO, Rome. Licence: CC BY-NC-SA 3.0 IGO; Popkin, B.M., Corvalan, C., Grummer-Strawn, L.M., 2020. Dynamics of the double burden of malnutrition and the changing nutrition reality. Lancet*. doi:https://doi.org/10.1016/s0140-6736(19)32497-3.

vegetables, and pulses (Herforth and Ahmed, 2015), contributing to food insecurity.

Indeed, in recent decades the agri-food system has significantly increased its production of fast foods and ultra-processed foods, including within the developing world (Herforth and Ahmed, 2015). The greater availability of inexpensive, tasty, and energy-dense foods and improved distribution systems that make such foods more accessible have been identified as two of the probable drivers of the global obesity pandemic (Swinburn et al., 2011). Demonstrating that point, Swinburn et al. (2011) point to high-income countries, which since the 1970s have experienced an important comovement as increased food energy supply appeared to increase food energy intake, population weight, and the prevalence of obesity.

Given the above, integrating nutrition in the availability pillar of food security is an essential step toward achieving food security. This may be pursued in multiple ways: nutrition-sensitive intervention strategies to enhance nutrition-sensitive food production systems, nutrition-focused import/export policies, nutrition-motivated fiscal policies (subsidies and taxes) to guide agri-food production, and promotion of agricultural research for enhanced nutritional aspects of food production.

At a fundamental level, the continued production of nutritious food relies on agricultural production, which in turn relies on the maintenance of sufficient nutrients in the soil. Crop yields and the nutritional content of crop-based foods are in part determined by the quality of the soil in which they are grown. Concerning the latter, the crop content of iron, iodine, selenium, and zinc—trace elements that humans must obtain from food or other sources, as they cannot be synthesized—are linked to soil factors (Oliver and Gregory, 2015). The degradation of soil and its detrimental effects on the quantity and quality of food production thereby threatens food security and human nutrition (Lal, 2009). The extent of human-caused soil degradation of agricultural lands is significant, with negative implications for food security (Oliver and Gregory, 2015). However, evidence exists that interventions to improve soil health can improve the quality of agricultural production, with positive effects on human nutrition: one study found that the application of zinc fertilizer to deficient rice fields led to nearly a doubling of zinc intake of children in northeastern Thailand (Shetty, 2009). Ensuring adequate nutrition in the future requires that necessary nutrients continue to be present in the foods produced by the agricultural system, which in turn must be supported by healthy soils.

Efforts have been made in lower-middle-income countries over the past decade to promote nutrition-sensitive agriculture, or agricultural programs that incorporate nutrition goals with the objective to promote more diverse and nutritious food consumption, either through direct consumption or through income via market sale. Programs have included agriculture extension, irrigation improvements, home food production, nutrition-sensitive value chains, production of livestock and dairy, aquaculture production, and biofortification (Hawkes et al., 2020). Available evidence shows that nutrition-sensitive agriculture programs effectively increase households' access to nutritious foods and raise the diet quality among mothers and young children (Ruel et al., 2018).

There exist several prominent examples of biofortification to improve the quality and quantity of nutrients within foods. One is the development by the International Rice Research Institute of golden rice, which contains beta-carotene, as a way to improve the nutritional status of populations with elevated rates of vitamin A deficiency (Dubock, 2019; International Rice Research Institute, 2018; Tang et al., 2009). Another example is the development of new varieties of sweet potato, a staple food produced and consumed in many parts of Africa, that offer enhanced nutritional quality and pest resistance. The orange-fleshed sweet potato, which is biofortified with provitamins to yield a vitamin A-rich potato, has led to significant reductions in vitamin A deficiency in sub-Saharan Africa (Low et al., 2017). Elsewhere, the Pan African Bean Research Alliance has developed and released over 450 new bean varieties that are resilient, high yielding, nutritious, and marketable, offering positive effects on the nutrition and health of rural and poor urban communities and vulnerable groups. The release of 41 high-iron and zinc-rich bean varieties has contributed to reductions in anemia among women and vulnerable children (Buruchara et al., 2011). Government policies support such biofortification programs to meet persistent macro- and micronutrient deficiencies.

In terms of food manufacturing, fortification, biofortification, and reformulation of foods can improve their nutritional content with an aim to improve food security and reduce malnutrition (Hawkes et al., 2020). For example, although food manufacturers directly control the content of the processed foods that they produce, governments can take action to guide their production so as to limit or reduce the energy density and levels of nutrients of concern such as salt and added sugar (Swinburn et al., 2013: 27).

In countries where the nutrition transition toward unhealthy diets, featuring calorie-rich foods including processed foods, has not yet occurred, preventive actions may be appropriate. Indeed, "It may be easier to promote healthy food environments where norms already support their consumption, rather than try to improve their desirability and shift norms after eating and nutrition transitions have already taken place" (Herforth and Ahmed, 2015: 511).

Many issues related to the production of nutritious foods merit further research. Researchers have underscored the importance of this research in achieving food security. In addition to established efforts to increase the nutrient content of staple foods, the research could usefully target the development and marketing of nonstaple, nutrient-rich foods. For example, research efforts could focus on developing appropriate seed production systems, ensuring the marketability of such crops, improving the infrastructure to reduce losses at the postharvest stage, and improving their processing to increase the convenience of consumption (Herforth et al., 2015). Efforts to improve communication between agricultural producers and nutritionists through the development of a systematic, consistent vocabulary for crop and cultivar nutritional content are a recent and concrete step in that direction (Halimi et al., 2019). In terms of interventions that promote the availability of nutritious foods, Herforth et al. (2015) propose working across agri-food value chains to identify leverage points that could enhance the dietary diversity and nutritional value of the foods produced. "These opportunities include: identifying bottlenecks where unnecessary transaction costs exist; decreasing costs and/or increasing the value of the commodity (through processing, for example); understanding production versus consumption dynamics; creating demand by understanding and influencing consumer choice; and identifying policy and regulation actions and solutions" (Herforth et al., 2015: 459). Finally, there is a need to generate robust evidence on which interventions are successful, under which conditions. To that end, the FANRPAN network has prioritized nutrition-sensitive agriculture in its most recent strategy to support evidence-based public policies (European Alliance on Agricultural Knowledge for Development, 2017).

1.4.2 Access: nutritional considerations in access to food

Although available, many people do not have access to nutritious foods due to a lack of physical, economic, and social access to them, which threatens their food security situation. We briefly highlight the relationship between each type of access and nutrition in this subsection.

Physical access to a given food affects dietary choices, as "a food cannot be consumed if it is not available at all" (Herforth and Ahmed, 2015: 507). Physical access (proximity) to food is at least partly the result of the built environment, or the presence of food entry points in the market and the supporting infrastructure to distribute food (especially perishable food) and bring it to consumers.[12] Areas without access to food may be found in low-, middle-, or high-income countries and are termed food deserts (geographic areas where access to food is restricted or does not exist, due to the absolute or relative lack of food entry points within a practical distance) or food swamps (geographic areas marked by an abundance of low-

[12] Consumers' access to the built environment varies as a function of their mobility (distance to food entry points and available transportation); health and disability conditions; purchasing power to buy food; time and facilities or equipment available to cook; and their knowledge and skills to prepare and use the food in their environment (HLPE, 2017).

quality, unhealthy food and insufficient access to healthy foods including freshly produced or minimally processed foods). Both food deserts and food swamps are associated with low incomes (HLPE, 2017).

Economic access to food (or affordability) is a function of the cost of food relative to a household's income and purchasing power (HLPE, 2017). Evidence from both developed and developing countries consistently shows that a healthy diet is more expensive than an unhealthy diet (Herforth and Ahmed, 2015). For example, a meta-analysis of available studies found that, in some countries, healthier food-based dietary patterns were on average more expensive than less healthy patterns, whether on the basis of actual consumption or on a calorie basis, by approximately \$1.50 per day or \$550 per year (Rao et al., 2013). Moreover, the cost of micronutrient-rich foods has risen over time, controlling for inflation (Herforth and Ahmed, 2015).

The concept of social access refers to the ability to access food through social arrangements, whether in terms of the use of common, nonfinancial resources available to all members of a community; the provision of food through social safety net programs; or the distribution of food within the household (Inter-American Institute for Cooperation on Agriculture, 2012; Kavishe and Mushi, 1993). Social aspects that have been identified as influencing access to food include gender, ethnicity, and social class (Bastakoti and Doneys, 2019; Odoms-Young and Bruce, 2018; Nagata et al., 2015; Valdivia and Gilles, 2001).

Box 1.2 highlights the effect of an evolving food retail landscape on food accessibility, as well as nutrition outcomes, around the globe.

As in the case of availability, actions and interventions to improve food accessibility can similarly focus on access to nutritious food. Such actions may take different forms—whether focused on improvements to a farmer's own production, to a nonproducer's purchase of food, or to food received through assistance programs—but all should focus on the provision of safe and nutritious food. For example, government policies can help shape the food environment, notably by ensuring physical access to nutritious food and reversing the obesogenic nature of current food environments (Swinburn et al., 2011). Economic access is intertwined with poverty alleviation, and in this way countries' efforts to alleviate poverty, increase income, and improve economic access should help pave the way to food security; however, more targeted action can also be taken. For example, to inform policy interventions, the research could usefully explore questions around access to nutritious foods, diet quality, and food safety (Herforth et al., 2015). In addition, growing evidence points to the role of fiscal policy in influencing the affordability of nutrient-rich foods. For example, subsidy reforms that improve nutrient diversity constitute an important step toward food access, and therefore food security. Analysis suggests that lower prices are the most effective ways to increase the consumption of nutrient-rich nonstaples (Herforth and Ahmed, 2015). Indeed, available evidence suggests that actions to reduce the price of fruits and vegetables have been associated with increased consumption of these foods (Herforth and Ahmed, 2015). Similarly, evidence from the United States found that both higher prices on unhealthy food and lower prices of fruits and vegetables were associated with lower weight outcomes, suggesting a role for both taxes and subsidies to influence public nutrition outcomes (Powell et al., 2013); an earlier study from the United States suggested that large tax increases may be more effective policy levers than either small tax increases or subsidies in provoking dietary changes that reduce BMI and the prevalence of obesity (Powell and Chaloupka, 2009). As for social access, public assistance programs can focus on the provision of nutritious foods to those in need. Egypt, which has offered food subsidies for decades, adopted in 2014 significant reforms of its food subsidy program to shift from provision of a

BOX 1.2

Supermarkets, food access, and nutrition

The entry and growth of large-format, self-serve retailers (supermarkets) in food retail have shaped food environments around the globe (Reardon et al., 2003; Reardon and Hopkins, 2006). This supermarket revolution has affected food security and particularly food access. Supermarkets have influenced physical access to food in some communities: larger food retailers may physically displace smaller retailers, leading to the phenomenon of food deserts, often in economically disadvantaged communities (Lee and Lim, 2009; Gatrell et al., 2011), with a negative effect on household food security. Moreover, the nutritional value of food provided by supermarkets: supermarkets and their global food supply chains have increased year-round accessibility of fresh foods in higher-income settings, but also energy-dense processed foods offering little nutritional value in lower-middle-income countries (HLPE, 2017). Indeed, the effect of supermarkets on the quality of diets may depend on the quality of the initial or traditional diet consumed before the entry of supermarkets (Qaim, 2017). As for supermarkets' role in expanding economic access to food, the evidence is mixed (Hawkes, 2008): supermarkets may reduce food prices, making food more affordable, although this may be delayed until supermarkets achieve economies of scale and pass savings on to their customers (Woldu et al., 2013). Moreover, evidence suggests that supermarkets may reduce the price of processed and packaged foods relative to fresh produce (Traill et al., 2014), making them relatively more affordable and promoting their consumption.

Recent research has explored the effect of supermarkets on consumer food choices and nutrition outcomes in developing countries. For example, Kenyan supermarket shoppers were found to pay lower average food prices per calorie, contributing to higher total energy consumption, and to have a higher dietary diversity (Rischke et al., 2015). In terms of nutritional outcomes, supermarkets have contributed to higher BMI and risk of overweight or obesity among adults in Kenya but decreased the risk of severe stunting among children and adolescents (Kimenju et al., 2015). Consistent results were found in Guatemala (Asfaw, 2008) and a wider, cross-country study (Kimenju and Qaim, 2016).

few, nutrient-poor items to a voucher-based program covering a basket of 30 food items, with a goal to improve access to diverse, balanced diets (Ecker et al., 2016).

1.4.3 Utilization: nutritional adequacy and safety of food

Food utilization, one of the four pillars of food security, pertains to the biological processing of food by individuals. It is clearly tied to nutrition to the extent that the terms "utilization" and "nutrition" are sometimes used interchangeably. Utilization, as it relates to food security, requires securing a diverse and healthy diet that provides sufficient energy and essential nutrients focusing on proper utilization of the food and nutrients in the body. Utilization requires basic knowledge of nutrition and proper childcare and health. It emphasizes the safety of the food consumed, which necessitates adequate sanitation; proper food preparation, processing, and storage techniques; and availability of potable water. By ensuring sufficient energy and nutrient intakes, as well as safe food, food utilization significantly influences the nutritional status of individuals, which is typically measured by nutritional indicators (Nordin et al., 2013).

Food utilization should be at the core of interventions to address food insecurity. Food utilization requires not only food access, but also food nutrient quality, food safety, safe drinking water, and proper hygiene; thus securing a diverse and healthy diet that provides sufficient energy and essential nutrients focusing on proper utilization of the food and nutrients in the body.

The case of India represents a stark illustration of the need for both nutritious food and supporting complements, specifically sanitation services. India is home to approximately 65 million children under the age of 5 who are stunted. These children are found even among the country's richest households. Research suggests that it is the practice of open defecation linked to a lack of clean water and sanitation to blame: children are exposed to bacteria that make them sick and unable to achieve healthy body weight, regardless of how much food they consume (Harris, 2014). Children's bodies use the available energy and nutrients to fight infections, limiting their growth and brain development in ways that are permanent. Beyond India, experts have estimated that the problem of poor sanitation may be the cause of approximately 50% of global stunting (Harris, 2014). Indeed, countries in which more of the population does not have access to safe water and sanitation services also tend to have a higher prevalence of food insecurity (FAO et al., 2019).

Food utilization is clearly tied to the issue of nutrition, and, accordingly, policies and programs that seek to improve food security must ensure that every individual can consume safe and nutritious foods. Interventions to achieve adequate food utilization and address food security include intersectoral approaches and actions in the area of food safety, food security, and nutrition. Examples include nutrition programs; activities targeting both food safety and food security; poverty reduction development policies, plans and budgets, including a mechanism for financing nutrition and food safety activities; programs for the prevention of foodborne illnesses; interventions minimizing the impact of emergency situations on the nutritional status of the population; and promotion of healthy dietary practices through the life span.

One type of community-based intervention that can be tailored to different segments of the population so as to improve their respective food utilization is the nutrition education program. For infants and young children, interventions should promote among their caregivers' good nutrition practices for optimal growth and development. For example, the practice of combining breastfeeding with timely, nutritionally adequate, and safe complementary feeding offers protection from under- and overnutrition that can progress into overweight, obesity, and adult-onset chronic diseases. Interventions targeting both school-aged children and adults can focus on practices such as the selection of healthy food choices including safe and nutrient-dense foods. Taken together, interventions that promote nutritious food to consumers can create a positive feedback loop via markets, increasing demand for the production of nutritious foods through the agri-food system. An example of a successful nutrition education intervention from the Middle East and North Africa (MENA) region is highlighted in Box 1.3.

Shifting dietary practices and the ongoing nutrition transition, if not halted or reversed, may threaten the food security of millions of people who will consume foods of insufficient quality by compromising their intake of macro- and micronutrients. The continued decline in consumption of, for example, fruits and vegetables may result in declining intakes of a wide range of vitamins and minerals, which are essential to the functioning of a healthy body.

BOX 1.3

Nutrition education interventions in MENA

Lebanon's "Nestlé Ajyal Salima" nutrition education program was launched in 2010. This program seeks to address the rising prevalence of overweight and obesity among youth in this small country in the Middle East. The program is based in the school setting, and it targets 9–11-year-old children and their food environment at the level of the classroom, school, and home. Program interventions in the classroom include interactive learning sessions and hands-on activities focused on nutrition; in the school, a food service component involves school shops; and at home, there is a family educational component (Habib-Mourad et al., 2014a). The program proved effective in expanding students' nutritional knowledge and self-efficacy, and in lowering the purchase and consumption of high-energy snacks and beverages by the students (Habib-Mourad et al., 2014b). The success of the program has led to its replication in other countries of the region, including Jordan, Palestine, and the United Arab Emirates.

1.4.4 Stability: conflict, environmental crises, and economic shocks

The stability dimension of food security pertains to the three other pillars: availability, access, and utilization. For example, war can disrupt food production in agricultural areas, limit household incomes or raise the price of food to make it unaffordable, or limit the necessary complements needed to utilize food (e.g., clean water).

1.4.4.1 Conflict

The prevalence of food insecurity is lower in countries that are more politically stable and subject to less violence (FAO et al., 2019). This correlation between wars and crises and food security has been demonstrated in recent years, particularly in the Middle East region. For example, countries in Western Asia that experienced conflict and uprisings reported an increase in the PoU from 17.8% in 2010 to 27.0% in 2018, whereas countries that did not experience such conflict reported no change in the PoU over the same period (FAO et al., 2019).

Interventions to address food insecurity in conflict situations must consider nutrition. For example, interventions that directly provide food to the displaced or the underprivileged should determine appropriate food baskets based on the macro- and micronutrient content of the food. Staple foods such as oil, sugar, and flour may help meet energy needs, but lack the protein and micronutrients needed for adequate growth and maintenance. More recently, emergency feeding programs have been redesigned to deliver food baskets and/or voucher-based assistance that delivers the essential macro- and micronutrients that are vital for human health and well-being, as the World Food Programme has done in its interventions supporting Syrian refugees displaced in Jordan, Lebanon, and Turkey. The design of emergency feeding programs must continue to balance food availability, recipients' preferences, and dietary diversity targeting food security and optimum nutrition.

1.4.4.2 Environmental crises

Environmental crises and shocks are also negatively associated with food insecurity. For example, drought-sensitive countries in sub-Saharan Africa experienced an increase in the PoU from 17.4% to 21.8% between 2012 and 2018, while in other countries of the region the PoU fell from 24.6% to 23.8% during that period (FAO et al., 2019).

Global climate change represents a critical challenge that threatens current and future food security, especially for the poor and vulnerable. The impacts of climate change will affect food security across all four of its pillars. For example, changes in climatic conditions are expected to affect the production of staple crops, with higher average temperatures and decreased rainfall affecting crop yields and quality, and thus food availability. Food access may be reduced as climate change drives up the prices of major agri-food crops. Climate change may affect the nutritional value of crops, affecting the ability of individuals to consume both sufficient calories and nutrients (Aberman and Tirado, 2014).

One concern linked to climate change and specifically the shifting composition of the atmosphere is the continued production of sufficiently nutritious crops. While higher concentrations of atmospheric carbon dioxide (CO_2) may stimulate faster growth in some food crops, the impacts on plant chemistry may lead to a reduction in the nutritional quality (concentrations of protein, micronutrients, and B vitamins) of staple crops such as barley, rice, wheat, soybean, potato, and legumes (Taub et al., 2008; Myers et al., 2014; Ebi and Ziska, 2018; Zhu et al., 2018). The impacts of these changes in nutritional quality may be significant in terms of public health. For example, Weynant et al. (2018) estimated the effects of elevated atmospheric CO_2 in lowering the concentration of zinc and iron in food crops, at an additional 125.8 million disability-adjusted life years between 2015 and 2050 due to infectious disease, diarrhea, and anemia; these effects were calculated to be greatest in Southeast Asia and Africa.

The negative impacts of climate change on food security, dietary diversity, care practices, and health may lead to a vicious cycle of disease and hunger. To avoid these outcomes, policymakers must adopt a systems approach to food security that goes beyond promoting agricultural productivity alone to encompass issues related to nutrition and public health. Actions taken now may help to limit the worst effects of climate change, including a reevaluation of land use and global agricultural practices to increase productivity and reduce food losses; and the promotion of shifts in consumer behaviors to decrease food waste as well as to reduce consumption of animal-based foods, particularly meat (Mbow et al., 2019).

1.4.4.3 Economic shocks

According to FAO et al. (2019), between 2011 and 2017, increases in the incidence of hunger were principally observed in countries with slower economic growth. In countries facing a food crisis, adverse economic shocks have extended and deepened the severity of acute food insecurity. The effects of economic contraction on food security and nutrition have been more harmful in situations already marked by high levels of income or resource inequality. "Left unattended, these trends may have very unwelcome implications for malnutrition in all its forms" (FAO et al., 2019: viii).

Common coping strategies in reaction to the economic crisis may include reducing or skipping meals, or shifting to less desirable (and less nutritious) foods. For example, evidence from Lebanon shows that the intake of important nutrients including calcium, zinc, iron, and folate all fell following previous food price shocks (Abou Zaki et al., 2014). The ability of households to buy food of appropriate quality and apply safe food handling practices may come under pressure as resources become scarce.

1.5 Conclusion

Efforts to tackle food insecurity have historically focused on agricultural production and the quantity of food, with insufficient attention to issues of accessibility, food quality, and consumption practices. Moreover, today's food systems are increasingly leading to adverse nutrition outcomes (GLOPAN, 2016), reflected in rising rates of overweight and obesity. Taken together, these findings indicate that renewed attention to the interwoven issues of food insecurity and malnutrition is needed.

Nutrition is an integral component of food security. Therefore food security cannot be achieved without proper attention to the issue of nutrition. Interventions, programs, and policies to promote food security—across all four pillars of its pillars—should incorporate nutrition accordingly. Promising areas for intervention include nutrition-sensitive agricultural research and development targeting food availability, policies promoting food access, and education that targets food utilization by end-consumers. Research must guide future work on food systems, and assist governments to introduce measures that ensure all people have access to nutritious food and can make informed choices about their diets.

Looking forward, actions to tackle food insecurity and malnutrition require working across disciplines, organizations, and borders. To this end, a food systems approach is essential to guide these efforts and deliver healthy, safe, and affordable diets for all. "Meaningful change will require action across food systems... driven from the bottom up by communities, cities, regions, and nations" (Branca et al., 2019: 1). For this change to happen, policymakers must focus efforts that look beyond agriculture to consider all parts of the food system, including production, processing, storage, transportation, trade, transformation, and retailing. National governments must take a decisive role in implementing policies that will lead the way to achieve food security and nutrition for all.

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CHAPTER

2

Transition toward sustainable food systems: a holistic pathway toward sustainable development

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2.1 Introduction

An estimated half of the global population does not have access to healthy diets, yet agriculture is today identified as a key sector contributing to greenhouse gas (GHG) emissions and water scarcity (Organization et al., 2017). In addition, the impacts of volatile weather conditions on food access and stability have been witnessed on a global scale, which has been related to increases in food prices and increased inaccessibility in hot spots. This presents one of our era's grandest challenges, to increase food production on a global scale while staying within the capacity of our planet to deliver other ecosystem services for present and future generations (Tsioumani, 2019). A food system that is sustainable, healthy, and inclusive is, therefore, a precondition to achieving the 2030 Agenda for Sustainable Development (United Nations Sustainable Development Goals [SDGs] 2030).

Identifying the parameters for such broad-scale goals is another challenge to address. The multiindicator sustainability assessment model that was developed by Gustafson et al (2016) presents a unique opportunity for a holistic assessment of food systems. In this model, Gustafson et al. (2016) adopted 25 sustainability indicators across seven main domains: (1) food nutrient adequacy, (2) ecosystem stability, (3) food affordability and availability, (4) sociocultural well-being, (5) food safety, (6) resilience, and (7) waste and loss reduction. In order to achieve the SDGs, the transformation of food systems must focus on

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food for health, value farmers, protect consumers from poor quality and unhealthy food, and maintain or improve ecosystem health.

Given this, the main aim of this chapter is to discuss some ideas for transitioning to sustainable food systems. It starts with a discussion of sustainable food systems and then follows with sections for each of the five pillars of sustainability (*5 Ps*) based on the framework adopted by the UN General Assembly (2015). Each "P" of the framework, that is, people, planet, prosperity, peace, and partnership provides the basis for discussing the various issues for the transition to a sustainable food system. The chapter concludes by gleaning out key issues from the 5 Ps sections and summarizing key factors that could help in the transitioning to sustainable food systems.

2.2 Sustainable food systems

The SDGs were adopted by the United Nations to address the global challenges especially related to poverty, hunger, malnutrition, inequality, climate change, environmental degradation, peace, and justice. Although SDG 2 was adopted to achieve "Zero Hunger," it is essential to recognize that food systems are at the center of the SDGs with contributions toward most of the 17 goals (Box 2.1). The SDGs, therefore, call for a holistic approach toward addressing the most urgent and universal challenges, as well as a move away from the silo approach that was the universal standard (United Nations, 2015). Given the substantial interactions among the SDGs (ICS, 2019) and their connection to the global food systems (FAO, 2019), achieving the sustainable

FIGURE 2.1 The "5 Ps" that shape sustainable development (Nassar, 2017).

development agenda will very much depend on the successful transformation of our current food systems (shift to a sustainable food system) to tackle the main global challenges in a sustainable, healthy, and inclusive manner.

The concept of sustainable development has evolved from the traditional framework comprising of social inclusion, economic growth, and environmental protection (Brown and Rasmussen, 2019). Since the adoption of the Sustainable Development Agenda 2030 (SDA 2030), two critical components were added for a more holistic framework of sustainability: *peace and partnership* (United Nations, 2015). It has since become a widely accepted model for genuine sustainability to be centered on five key components: *people*, *planet*, *prosperity*, *peace*, *and partnership* (Fig. 2.1) (Box 2.1) (United Nations, 2015; Nassar, 2017). This model was designed to integrate aspects of economic, social, and environmental dimensions, for better management of the synergies and trade-offs. These five components—the "5 Ps"—represent a crucial aspect of the SDGs and the interrelations between the various goals.

As food systems are central to the achievement of the SDGs, this chapter will discuss the contribution of sustainable food systems toward achieving the SDGs through their contribution to the "5 Ps." We argue that for the world to achieve sustainable development, a shift to sustainable food systems is necessary to ensure food security, good nutrition, and health while promoting ecological and economic resilience,

BOX 2.1

Sustainable Development Goals and food systems in a nutshell

As of 2015, the world had agreed to 17 SDGs with 169 targets associated with these goals (United Nations, 2015). This has been followed by a drive to measure progress toward the SDGs, which has seen an explosion in the development of indicators and metrics to monitor progress (Reyers et al., 2017). There are some key challenges in monitoring progress toward the SDGs, central of which is the nature of the goals themselves. The SDGs address a very broad and multifaceted range of fields—from reducing inequalities to conserving life on land and below land—which can further be complicated by the interactions and interlinkages between the targets.

A key principle of the SDGs was to provide an intertwined framework for coordinated action, which can at times be overlooked when focusing on the specific indicators and metrics (Reyers et al., 2017). These goals were built on five pillars—people, planet, prosperity, peace, and partnership. By focusing on these "5 Ps," the true framework of the SDGs can be observed and allow for an approach that works toward sustainable development. Thereby, focus is shifted away from the silo approach, toward an approach that is respectful of the interlinkages and allowing for progress across all pillars that supports each other.

This approach is equally valuable in our transition toward a sustainable food system. It is important to consider the interlinkages between the different components of this system and perceive how progress on one end could impact progress on the other end. Similar to the SDGs, focusing on the "5 Ps" as opposed to the different indicators and metrics would be a valuable approach for highlighting sustainability of our food systems.

reducing inequalities, promoting inclusion, contributing to peace, adapting to, and mitigating climate change.

2.3 Transforming food systems is the key to ending poverty, hunger, and malnutrition: *people*

2.3.1 Toward optimal health and nutrition

SDG 2 (Zero Hunger) aims to achieve not only food but also nutritional security. Many efforts have been directed toward food availability and calorie sufficiency, overlooking the need for a balanced diet to address malnutrition and the emerging problems associated with overweight and obesity. The sustainable development of people is dependent on their food security, nutritional, and health status, which in turn depends on the global food systems. The current global food system has been implicated in hunger and malnutrition, which are central to current global health concerns. Globally, the proportion of the undernourished population has been on the rise.

A general shift in consumer demands toward unhealthy foods coupled with a decrease in physical activity has occurred in both developed and developing countries (Organization et al., 2017; Popkin et al., 2019). Globally, a surge in the consumption of globalized diets with increased salt, sugar, and animal-based proteins (Organization et al., 2017) has been witnessed. A global dietary transition away from traditional diets is in motion as the global food system has transformed toward the increased provision of cheaper, accessible, and less nutritious foods (Popkin et al., 2019; Tilman and Clark, 2014).

As such, we see that malnutrition existing in multiple forms (triple burden of malnutrition: undernutrition, micronutrient deficiency, and overnutrition) can overlap in various ways within the same segment of the population (Popkin et al., 2019). An estimated 2.28 billion children and adults worldwide are overweight or obese, while 821 million are undernourished, of which 150 million children are stunted (FAO et al., 2018; Wells et al., 2019). The prevalence of undernutrition was generally associated with factors of poverty, food insecurity, and diseases and infection, while obesity was linked with aspects of affluence and sedentary behavior (Wells et al., 2019). However, the coexistence of both health burdens can occur within the same communities (Wells et al., 2019); known as the double burden of malnutrition (Popkin et al., 2019).

The triple burden of malnutrition has been increasing, especially within populations with low incomes and in impoverished areas of low- and middle-income countries (Popkin et al., 2019). Older statistics on population health and food security focused on caloric and protein intake, thus overlooking micronutrient intake (Chaudhary et al., 2018). Deficiency in micronutrient intake—known as hidden hunger—affects an estimated two billion people worldwide (Chaudhary et al., 2018). Key micronutrient deficiencies are reported in iron, iodine, folate, vitamin A, and zinc; which contribute toward poor growth, intellectual impairments, prenatal complications, morbidity, and mortality. Within children, this is widely reported as stunting and wasting, and its impacts can persist into adulthood, as evidence shows that an increasing number of overweight individuals were undernourished earlier in life (Wells et al., 2019).

The consumption of diverse diets that comprise of a myriad of food groups is essential to address this challenge (Mustafa et al., 2019b). Efforts to address food availability, affordability, convenience, and consumer behavior are crucial in tackling issues surrounding malnutrition holistically. To realize the goal of optimal health and nutrition, efforts must be directed toward addressing

BOX 2.2

Four essential ingredients to end rural poverty

While there is no one-size-fits-all solution, FAO proposes a recipe to leave no one behind that includes four basic ingredients:

Investing in agriculture and rural areas to address the structural constraints that poor rural people face. This includes improving their access to resources, services, infrastructure, technologies, markets, and extension services, to increase their productivity and income. While evidence shows that investing in agriculture is more effective in reducing poverty than investing in other sectors, this is not enough to lift people out of poverty. Because climate change, food prices volatility, and political tensions hinder food production, rural people need to diversify their income to build resilient livelihoods.

Creating more and better jobs in rural areas, especially for young people. Income diversification and job creation give people a chance to stay in rural areas, thus reducing distress migration. In 2015, of the 244 million people who crossed the border in search of a better life, about one-third was between 15 and 34 years old. Many young migrants come from developing countries, particularly from rural areas where poverty, famine, and protracted crisis are preventing them from finding a job and build their future.

Social protection also matters when it comes to addressing the needs of the most vulnerable people. Measures such as cash and asset transfers or targeted subsidies for the poorest help them cope with risks and shocks to their livelihoods. By providing a minimum income, these measures relax insurance and credit constraints, allowing poor rural people to start businesses and facilitating their transition into income-generating activities. This also improves their nutrition, education, and health status.

One last ingredient is *policies*, and in particular multisectoral policies to end poverty. Because poverty is a complex issue, policies that address only one root cause are not sufficient. Only broad multisectoral approaches that bring coherence and coordination between policies to boost agriculture, foster rural development, and eradicate poverty can deal with this complexity. Government and Parliaments therefore have a key role to play in meeting SDG1.

Source: Based on FAO, 2017. End rural poverty: a path towards hunger-free, peaceful and inclusive societies. In: Sustainable Development Goals. <http://www.fao.org/sustainable-development-goals/news/detail-news/en/c/1044650/>.

numerous drivers, including individual and institutional factors to shift consumer behavior and fix both supply and demand side of the food environment including aspects related to food loss and waste. The food system is not the only aspect that needs to be addressed, but the environment in general. Obesogenic environments are on the rise (Wells et al., 2019), as technological advances in transportation, communication, and so on limit the need for physical activity.

2.3.2 A path toward a poverty-free society

Poverty is a multidimensional concept and is defined by the World Bank as "encompassing low income and consumption, low educational achievement, poor health and nutritional outcomes, lack of access to basic services, and a hazardous living environment" (World Bank, 2018). The SDGs were developed with the central message of "leaving no

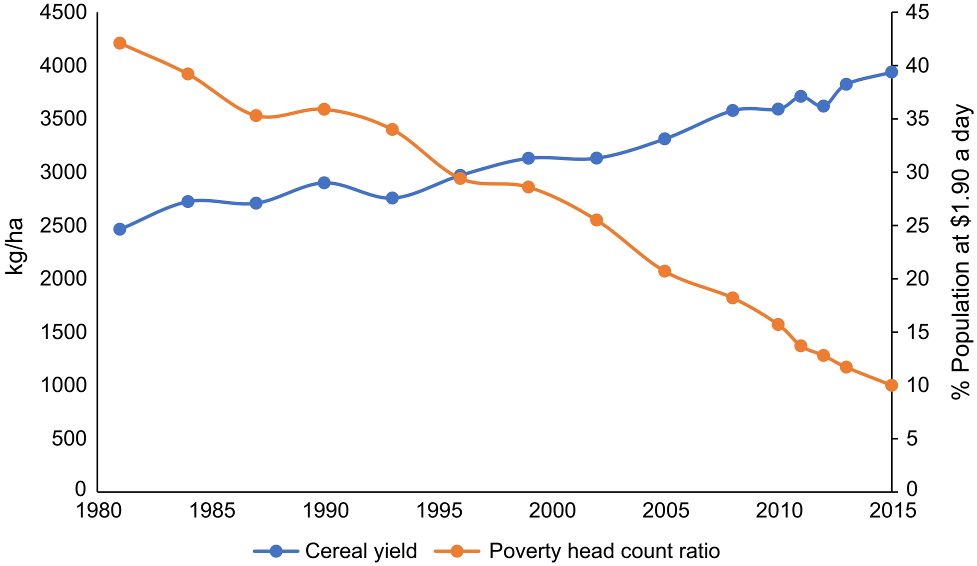

FIGURE 2.2 Poverty reduction has been closely correlated with higher yields in sub-Saharan Africa. *Data source: World Bank, 2019. World Development Indicators. The World Bank, Washington, DC. Retrieved from <https://datacatalog.worldbank.org/dataset/world-development-indicators>.*

one behind" (Box 2.2). As such, eradicating poverty is a central mission to achieving not only SDG 1 (no poverty), but several of the SDGs established in the Sustainable Development Agenda. Agriculture directly benefits smallholder farmers, rural women, youth, and indigenous communities, thereby playing an integral role in rural development and uplifting communities from poverty. Recognizing this, FAO positions poverty eradication through a rural transformation as a central theme in their 2017, 2018, and 2019 publications on "The State of Food and Agriculture." This highlights the need to have interventions that not only target poverty reduction but also address issues of health, food, and nutrition. No country has achieved prosperity without growth in productivity, especially the agricultural sector. The 2030 Agenda for Sustainable Development recognizes this and now addresses poverty and hunger, although, two distinct global goals, as mutually inclusive threats (United Nations, 2015).

Through the lens of agricultural development, poverty and hunger are perceived as impacting distinct groups due to the contribution of farming toward individual and household income portfolios (Dorward et al., 2001; Tittonell et al., 2010). Thereby, various technical and policy-based interventions are adopted to address the needs of these distinct groups. Nonetheless, a general consensus recognizes the enhanced agricultural productivity of smallholder farmers as an essential driver to alleviate poverty and ensure food security. Improved agricultural output has been seen to exhibit a positive correlation with poverty reduction. As evidenced in Fig. 2.2, higher cereal yields in sub-Saharan Africa over the past decade have been accompanied by an increase in the percentage of the population living above the $1.90 a day margin (the global indicator of extreme poverty) (World Bank,

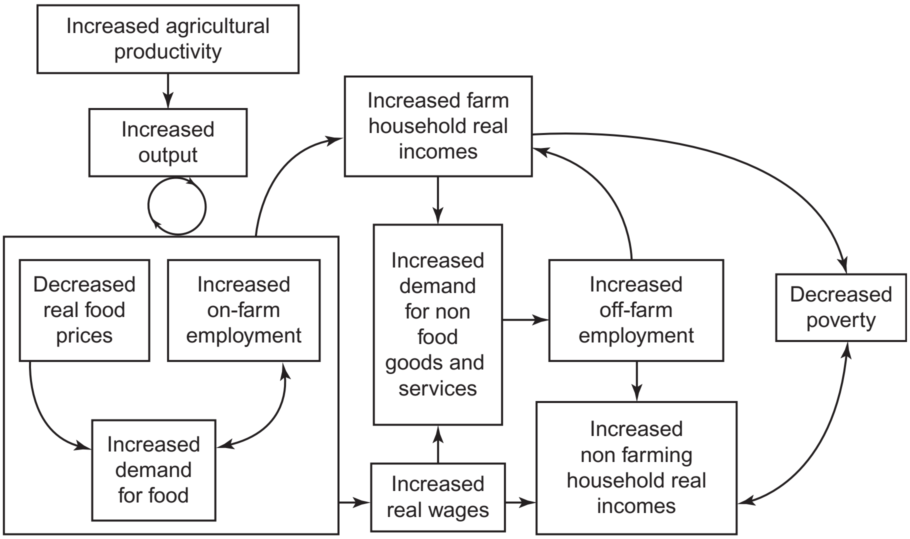

FIGURE 2.3 Pathways to decrease poverty through increased agricultural productivity. *Source: Schneider, K., Gugerty, M.K., 2011. Agricultural productivity and poverty reduction: linkages and pathways. Libr. Test J. 1 (1), 56–74.*

2018). However, it is not only enough to increase agricultural output, but farmers and farm workers also need to be protected from exploitation by multinational corporations. The latest iteration of this debate is still evolving around the idea of sustainable intensification (SI) (Godfray and Garnett, 2014).

In recent years, as more awareness has been raised with regards to the trade-offs between agriculture and the environment, there have been growing calls for a paradigm shift in agricultural systems toward greater sustainability. Part of these discussions has focused on how agriculture can continue to produce more food to feed a growing population, but without causing further environmental degradation, and also, how agriculture can have synergistic interlinkages with socioecological and socioeconomic systems. This has given rise to several forms of sustainable agriculture, all coined differently but with strong parallels, the most notable being SI. By definition, SI advocates for agricultural systems whereby gains in agricultural productivity are achieved while maintaining or improving socioecological and socioeconomic outcomes. This has to be context-specific and can be achieved through optimizing efficiencies and mitigating negative trade-offs while maximizing synergies between agriculture and the environment. The focus is on achieving sustainable socioecological and socioeconomic outcomes without negative environmental trade-offs. However, there is much complexity to achieving such balance, which is why in many cases, agricultural systems remain untransformed. Fig. 2.3 illustrates the complexity of increasing agricultural productivity while reducing poverty. Thus for transformation to occur, and get agriculture to deliver on environmental, livelihoods, and profitability outcomes, there is a need for partnerships.

2.3.3 Closing the gender gap in agriculture

Women play an important role in agriculture and rural development and contribute significantly to achieving food and nutrition security at household and community levels (FAO, 2010; Quisumbing et al., 2014). However, this role is hardly recognized. Approximately half of the agriculture labor force in Asia and Africa constitutes of women, (CGIAR, 2016; Fletschner and Kenney, 2011; Khachaturyan and Peterson, 2018) and being the primary caregivers within the household, they tend to use any income gained from agricultural activities to improve family welfare, especially child nutrition, health, and education (CGIAR, 2016). Women in rural areas engage in numerous agricultural activities, which include clearing of fields, sowing, weed control, harvesting, transplanting, cleaning of grain, processing, and livestock production. This is in addition to their unpaid household responsibilities of fetching water, cleaning their households, child-rearing, and taking care of their families. It is, therefore, no surprise that women face a time burden that leaves little time to pursue other productive activities, which will provide them with access to financial resources (FAO, 2019). Moreover, women do not have the same access to productive resources and opportunities as men, and this hampers their potential to make a significant contribution to the economic development of rural poor (CGIAR, 2016).

Rural to urban migration and the prevalence of HIV and AIDS contributed toward the feminization of agriculture as more women were forced to replace men in agricultural activities (World Bank, 2009). This resulted in women becoming major actors in the sector as traders, processors, laborers, and entrepreneurs (World Bank, 2009). Despite this, women still lack access to land, agricultural inputs such as drought-resistant seeds and fertilizer, technology, education, extension, financial services, and markets (Quisumbing et al., 2014). The distribution of land ownership is heavily skewed toward men, and women tend to own smaller land than men (EIGE, 2016; FAO, 2019; World Bank, 2009). For example, in Latin America and sub-Saharan Africa, 70%−80% of the land is formally owned by men (World Bank, 2009). In addition, while women represent a significant share of the agricultural labor force, they receive lower remuneration than their male counterparts and have no job security (EIGE, 2016). Furthermore, very few women occupy managerial positions or participate in decision-making (EIGE, 2016).

In order to participate more effectively and compete in the market, and strengthen their role as producers, women need access to credit. The lack of finances is often cited as one reason that women use lower levels of inputs in agriculture (Quisumbing et al., 2014). Women, especially in rural areas, face numerous challenges in accessing credit due to sociocultural, economic/legal or educational barriers (FAO, 2019). These barriers include the time burden, which makes it difficult to travel long distances to financial institutions where they can deposit money, borrow, or repay their loans (FAO, 2019). Second, women generally do not possess productive assets or property that can be accepted by banks as collateral in order to secure a loan (FAO, 2019; Fletschner and Kenney, 2011). The situation is compounded by the fact that rural financial programs are generally designed with the male head of household as the intended client, and not women (Fletschner and Kenney, 2011). In order to empower women, socioeconomically, and ensure the success of rural development strategies, both men and women require adequate and equal access to financial resources (Fletschner and Kenney, 2011). The gender gaps that currently exist have resulted in the underperformance of agriculture. Improving women's access to resources, education, and opportunities can significantly increase income and the well-being of families (Quisumbing et al., 2014). This could also increase food production by women by 20%−30%, potentially reducing hunger for 150 million people (Duckett, 2019; Quisumbing et al., 2014).

Agriculture is central to the livelihoods of the rural poor and has the potential to reduce poverty and food and nutrition insecurity. The sector can also contribute to the attainment of the SDGs (World Bank, 2009). However, this potential is hampered by the gender gaps that exist and prevent women, who form more than half of the agricultural labor force, from fully engaging in the sector. As caretakers in the household, the constraints that women face need to be overcome. Gender equality is a basic human right and is crucial for agricultural development (World Bank, 2009). Transformative approaches need to be taken to tackle the underlying causes of gender inequality in agriculture in order to close gender gaps, ensure sustainable food systems, food and nutritional security, and achieve sustainable development and shared prosperity. This would also allow women to reach their highest economic potential, enabling them to spend more money on health care, nutrition, and education for their children (Duckett, 2019). Such investments can produce long-term, positive results for their families and communities (Duckett, 2019).

For sustainable futures for people and the planet, there is a growing recognition of the important role played by agriculture in ending poverty, hunger, and malnutrition (Caron et al., 2018). Furthermore, education and gender equity have been seen as central to achieving sustainable development and shared prosperity—people. Several development agencies call for a rural *renaissance* in which interventions are recrafted to suite their social, economic, and environmental context. It is central to the achievement of the SDGs, and the alternative is sustainable food systems that primarily address cross-cutting issues on planet, people, and prosperity.

As evidenced, food systems are not only a matter of food and nutritional security, but impact lives in multidimensional ways. From economic prosperity to gender equity, food systems are central to fulfill the potential for all human beings to live in dignity and equality. Yet this guarantee is incomplete without the efforts to protect and safeguard our planet.

2.4 Safeguarding our planet for future generations: *planet*

2.4.1 Planet and planetary boundaries

Food production is associated with huge environmental costs, such as GHG emissions, excessive use of water, and natural resources (The Lancet Planetary Health, 2017). The food system depends on a myriad of resources directly derived from the planet. Biodiversity, from species level to the ecosystem level, is the foundation of our capacity to produce food. Embracing biodiversity in agricultural systems (Mustafa et al., 2019b) is vital to strengthen resilience and enhance the productivity of food systems. Agricultural activities have a direct impact on the planetary boundaries (Rockström et al., 2017), and a broader understanding of the environmental impact of global food production systems is needed.

An increase in food productivity is often perceived as an indicator of efficient input use; however, this measure does not factor in environmental costs (Grovermann et al., 2019). A suggested indicator to balance efficiency and environmental sustainability is *eco-efficiency*, which is the ratio of economic value-added and environmental costs (Grovermann et al., 2019). This would require an assessment of GHG emissions, water footprint (WF), and land use. Indicators have been developed to quantify the environmental impact of the consumption of goods and services, such as carbon footprint, WF, and ecological footprint (Lovarelli et al., 2016).

The food system today is undermined due to current production and land-use practices, which are reducing diversity worldwide (Khoury et al., 2014). Large agricultural lands are made up of monocultures, with increasing dependence on external inputs such as fertilizers and pesticides (Khoury et al., 2014). On the positive side, better management practices that embrace diversity and are environment friendly

BOX 2.3

Gases considered for the purpose of carbon accounting (ERC, 2010)

There are a total of 18 GHGs with different global warming potentials, but under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto protocol, only the following set of gases is considered for the purposes of carbon accounting, with others being regulated elsewhere (ERC, 2010):

- carbon dioxide, CO_2
- methane, CH_4
- nitrous oxide, N_2O
- hydrofluorocarbons, HFCs
- perfluorocarbons, PFCs
- sulfur dioxide, SF_6

are increasing in popularity (Tsioumani, 2019). Biodiversity strengthens resilience and limits the negative impact on the environment and populations that are directly dependent on it, thereby supporting the livelihoods of communities of growers and food producers (Tsioumani, 2019). In this context, on- and off-farm diversification plays a key role in promoting resilience, improving livelihoods, and enhancing food security (Mustafa et al., 2019b).

The planetary boundaries define a safe operating space for continuing to provide for current and future generations. Sustainable agriculture is key to ensure that we stay within these limits, such as within a 350 ppm global carbon budget, or environmental water flows and land change (Rockström et al., 2017). This is essential for our bid to stay within the boundaries of 1.5°C global temperature rise.

2.4.2 Carbon footprint

Increasing literature is now available that provides a better interpretation of the environmental costs of food production. With that, considerable efforts are in place with the aim of minimizing the emissions of GHG (Box 2.3: 18 different GHG with different global warming potentials) and their associated negative impacts (Steen-Olsen et al., 2012). The special report on climate change and land by the Intergovernmental Panel on Climate Change (IPCC, 2019) estimated that 23% of GHG emissions are the result of agriculture-related activities. The report also emphasizes that food production is a major contributor to the climate challenges faced by the planet today. It is predicted that if the current dietary transition continues, food production could contribute by an increase of almost 80% in GHG emission and land clearing (Tilman and Clark, 2014).

The implementation of the Paris Climate Agreement has been slow, and the recent Conference of Parties (COP25) meeting concluded in disappointment with a failure to reach consensus in many key areas (Evans and Gabbatiss, 2019). The current global trajectory to curb GHG emissions still puts the planet on a pathway toward a 2.7°C increase in global temperatures (Organization et al., 2017). This will have detrimental impacts on the planet, and on our food systems resulting in an almost 84% increase in food prices by 2050 (Organization et al., 2017). Future scenarios with optimistic outcomes require a change in food systems. The transition toward sustainable food systems offers substantial health benefits, but also a reduction in carbon footprint as well as water and ecological footprint (Tilman and Clark, 2014).

BOX 2.4

Types of carbon footprint

The main types of carbon footprint are as follows:

Organizational: Emissions from all the activities across the food production system, including input manufacture, farm equipment, buildings' energy use, industrial processes, and vehicles.

Value chain: Includes emissions, which are outside a food production operation. This represents emissions from both suppliers and consumers, including all use and end-of-life emissions.

Product: Emissions over the whole life of a product or service, from the extraction of raw materials and manufacturing right through to its use and final reuse, recycling, or disposal.

Supply chain: Emissions from the raw materials and services that are purchased by a producer in order to deliver its service(s) and/or product(s).

Source: From Carbon trust 2020 Carbon footprint guide.

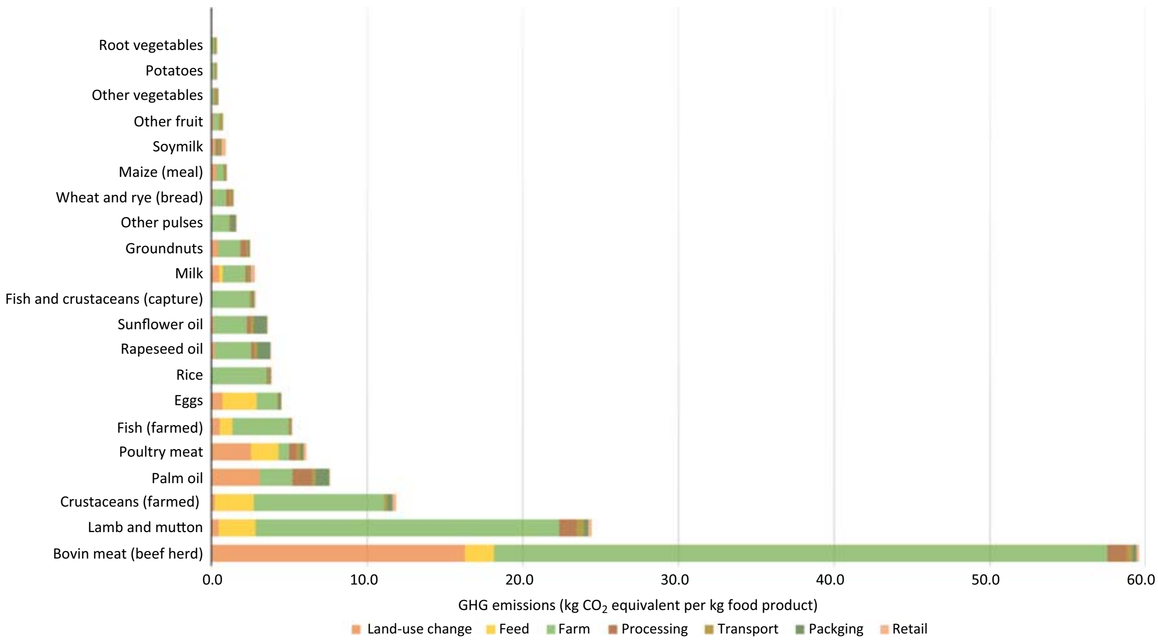

FIGURE 2.4 Greenhouse gas emissions for 21 different food categories across the supply chain (land-use change, animal feed, farm, processing, transport, packaging, and retail). *Date source: Poore, J., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science 360 (6392), 987–992.*

The transition toward sustainable food systems offers substantial health benefits, but also a reduction in carbon footprint as well as water and ecological footprint (Tilman and Clark, 2014). A carbon footprint can broadly be defined as a measure of the GHG emissions that are directly and indirectly caused by an activity or are accumulated over the life cycle of a product or service, expressed in carbon dioxide equivalents CO_2-eq (Energy Research Centre ERC, 2010). Recently, metrics have been developed by Clune et al. (2017) and Tilman and Clark (2014) to estimate the carbon footprint of agricultural activities. This is represented as total GHG emissions attributed to the consumption of a food product, in tons of CO_2 equivalent (Steen-Olsen et al., 2012). See Box 2.4 for the different types of carbon footprint.

Even though animal production systems emit more GHG per unit of food products than plant production systems (Fig. 2.4), huge variation exists between the different types of animal production systems (Clune et al., 2017). Beef is by far the largest emitter of GHGs, which is directly attributed to methane (CH_4) from enteric fermentation in addition to methane and nitrous oxide (N_2O) from manure (Reisinger and Clark, 2018; Clune et al., 2017). Animal production systems are also associated with the indirect emission of GHGs through the production of animal feed, the transformation of land for producing animal feed, and the GHGs associated with fertilizer production and use. As such, animal production systems (which are a valuable contributor of proteins) carry a much larger carbon footprint than plant-based foods, calling for a need to reassess protein sources for a more sustainable food system.

Essential recommendations required to bring the agriculture and food system into a safe operating space include the substitution of animal-based proteins with plant-based proteins, reduction of food loss and waste, and reduction of environmentally-negative agricultural production activities (Tilman and Clark, 2014). Plant-based foods and meat substitutes are a vibrant development with many new players entering the market with innovative product formulations. Plant-based proteins are also cheaper than animal-based ones (Steen-Olsen et al., 2012). In addition, there is a need for raising awareness of the impact of foods on climate change and resultant carbon footprint. However, raising awareness does not necessarily translate to behavior change, as consumers might need more drivers that reflect tangible and immediate benefit, to encourage the adoption of sustainable dietary habits.

2.4.3 Water footprint

Per capita use of water is a global concern, and freshwater is increasing in scarcity (Lovarelli et al., 2016). While on average, people would drink 2 L of water per day, the average per capita use of water can reach 3000 L (The Economist, 2008). An estimated 70% of freshwater withdrawals are attributed to food production, with almost 85% of ground and surface water is utilized (FAO, 2011). As global populations continue to grow, and food demands continue to move toward unsustainable habits, the global pressures on limited water resources will exacerbate water scarcity (Rockstrom et al., 2009). Water consumption has increased threefold over the past 50 years (Organization et al., 2017), and a further 55% increase in freshwater withdrawals are estimated by 2050 (Sokolow et al., 2019). Overexploitation of water can lead to critical economic, environmental, and social problems on a regional and global scale (Lovarelli et al., 2016). Therefore careful consideration of the social, environmental, and economic contexts within the water can help decision-makers build a sustainable food system meeting human and environmental health needs.

The link between food, nutrition, and freshwater resources for sustainable development is well established by the SDGs (United Nations, 2015). Although not explicitly mentioned within the SDGs, the link between food, health, and environmental initiatives, in this case, water for sustainable food production, can be used to establish common goals and targets within food systems. With regards to the global food system,

BOX 2.5

Reducing water footprints for sustainable food systems

Lower water consumption and more sustainable diets could be achieved through the following efforts:

- *Optimizing the food and nutrients produced for every drop of water used* (that is, increased "water productivity and nutritional water productivity"). This can be achieved by stimulating the demand for food with lower WF (e.g., Underutilized crop species (Natalini et al., 2019) and, informing and educating the consumer on environmental and nutritional impact of food in terms of water
- *Reducing food losses and waste* in production and supply chains, for multiple gains, among them, water savings;
- *Consuming diets to meet and not exceed food and nutrient requirements*, thus reducing the risks of nutrition-related diseases and disorders such as obesity, stunting, and hidden hunger, and lowering WFs. Literature has shown that a reduction in animal-source foods in the diet, particularly beef, poultry, and pork meat, corresponds with reduced environmental impacts and resource requirements; and more importantly WF.

Source: Adapted from FAO, 2010. Sustainable diets and biodiversity: Directions and solutions for policy, research and action. In: B. Burlingame, S. Dernini (Eds.), International Scientific Symposium on Biodiversity and Sustainable Diets.

there is large variability in water consumption, and this is mainly dependent on environmental, agricultural management, and food processing factors. The most commonly used metric for assessing water use is the "WF", which quantifies the volume of water consumed from field to plate (in liters per kilogram). As such, WF within global food systems can be used to quantify trade-offs and synergies within SDG initiatives that link food, health, and environment.

Mekonnen and Hoekstra (2014) developed metrics to measure the WF of various food groups, by quantifying the direct and indirect freshwater consumption in terms of green, blue, and grey water. Green water is an indication of rainwater consumed by the plants, whereas blue water represents the ground and surface water, and greywater is a measure of the water pollution due to emissions during food production (Steen-Olsen et al., 2012). The developed metrics attempt to create a better understanding between food production and the direct and indirect pressure it exerts on the shrinking water resources (Lovarelli et al., 2016). This is crucial in identifying sustainable diets for better health outcomes and minimal environmental impacts, specifically the effect of current food production practices and dietary patterns on the sustainability of water use. According to Jackson et al (2015), the WF for the global food system was 2038 km^3/year. This is expected to continue to grow and roughly double by 2030. It goes without saying that current activities on sustainable diets should aim to provide water-sensitive food recommendations (Box 2.5) that are formulated by technologies that aim for an environmentally sustainable food system.

This approach was also used to compare within food groups to assess the WF of crops and correlate it with the nutrient density (Mekonnen and Hoekstra, 2014). Fruits and vegetables were generally found to have a lower WF and higher nutrient density, in comparison to staple crops (Mekonnen and Hoekstra, 2014).

Moreover, native and traditional vegetables were assessed by Natalini et al. (2019) and found to have a lower WF and higher nutrient density compared with nonnative vegetables.

The sustainability of modern global food systems has been questioned, and there is a consensus that it needs to change. The continuing growth in global populations will exacerbate the challenge of increasing food production within the limited available resources. Nutrition transition in developed economies and among middle-class communities in developing economies has led to higher demands of animal-based food products and high-calorie food crops. These have a much higher demand on the already limited land and water resources. As such, there is an urgent need for a shift toward sustainable agricultural practices and diets that are nutrient dense with low WF. Healthy and sustainable diets coupled with sustainable consumption patterns will have multiple benefits across the environment, human health, and various other sectors, contributing to addressing most of the SDGs.

2.4.4 Ecological footprint

The ecological footprint was developed as a measure of the biologically productive land needed for meeting human needs (Steen-Olsen et al., 2012; Radomska et al., 2018). This includes food production and other aspects that contribute to the economy and well-being. In addition, ecological footprint provides an estimate of the impact that populations have on the environment through the use of natural resources, consumption of goods and services, and resultant carbon emissions (Radomska et al., 2018). As such, depending on the consumption habits of different populations and individuals, the ecological footprint can vary significantly (WWF, 2016). For example, the United Arab Emirates, at 10.68 global hectares per capita, has the largest ecological footprint in the world (Pariona, 2017). The majority of this footprint comes from the households and their energy use, vehicles, and private jets (Pariona, 2017). Conversely, many countries in Africa, Asia, and South and Central America have per capita footprints of less than 2 ha (Radomska et al., 2018). WWF (2016) notes that the area of productive land and sea available on earth amounts to only 1.4 ha per person, and this has been exceeded.

Over the past 50 years, humankind's ecological footprint has increased by approximately 190%, largely due to overexploitation and intensive (and extensive) agricultural practices (WWF, 2018). An estimated one-third of arable land is degraded worldwide, due to intensive farming practices. This has called for a move toward sustainable agricultural intensification and other practices that protect the land. Sustainable agricultural intensification seeks to increase agricultural productivity while maintaining the ecological footprint to a minimum (Rockström et al., 2017). This approach can be achieved by better management of farming fields, watersheds, and landscapes through the adoption of practices that maintain vital ecological functions such as carbon sinks and natural water cycles (Rockström et al., 2017). The adoption of sustainable agricultural practices offers a promise to address soil health, minimize chemical use, and diversify landscapes for improved human and environmental health (Mustafa et al., 2019a).

The continuous depletion of natural resources as a result of unsustainable agricultural practices is a global threat, which could be further aggravated by the pressures of a changing climate. Growth in population and rise in global affluence have played a key role in the depletion of natural resources; specifically, freshwater and productive land (Steen-Olsen et al., 2012). The food sector contributes to 23% of GHG emissions, of which an estimated half of it is due to land conversion (IPCC, 2019). Strong interconnections exist between the natural resources, influencing one another (Steen-Olsen et al., 2012). For example, loss of forest cover, mostly due to agricultural activities, is a major threat to the planet's biodiversity and capacity to provide ecosystem services, such as clean water, carbon sequestration, and soil conservation (Tsioumani, 2019). This loss in biodiversity and ecosystem functions directly threatens our capacity to produce food and options to mitigate and adapt to the changing climate (Chen et al., 2018).

Agriculture and other land-use activities account for a large proportion of GHG emissions and are drivers of climate change. On the other hand, food and nutrition security are increasingly affected by climate change, directly and indirectly, for example, yield declines due to droughts especially in the tropics, reduced nutrient quality, and supply chain and market disruptions (FAO, 2016). This, in turn, affects livelihoods, the stability of agricultural and rural incomes, and the ability of the poor to purchase nutritious food (FAO, 2016). The rural poor people are highly dependent on agriculture and natural resources for livelihoods, and this makes them most vulnerable (FAO, 2016). Therefore transforming our food systems through sustainable agricultural practices (Mustafa et al., 2019a) and responsible production, supply, and consumption activities to safeguard life on land and below is the key to farming our way out of the climate emergency and will save our planet for future generations. There also needs to be a detailed understanding of how the complex components of the food system, and actors involved, are interlinked, from source to the shelf (WWF, 2018).

2.5 Prosperity and peace

2.5.1 Commitment toward inclusivity and well-being

In this section, these two pillars are addressed concomitantly as the synergies and interactions between both pillars are immense. While prosperity focuses on the commitment toward prosperous and fulfilling lives for all, peace is centered on the commitment to inclusive and peaceful societies. For both aspects, economic and social progress that is in harmony with nature and communities is required (Brown and Rasmussen, 2019).

Agriculture is the largest employer globally, with an estimated 500 million small holder farmers who contribute towards the production of 80% of global food consumption (Chaudhary et al., 2018; Organization et al., 2017). However, farmers are not necessarily beneficiaries of their labor. This is particularly evident in economically poor countries where agriculture represents an important share of the national gross domestic product. However, it is important to note that various stages—such as production, processing, distribution—that make up the food chain and their contributions to employment and income generated differ across countries (Chaudhary et al., 2018).

Poverty and disproportionate access to wealth and resources mean that volatility in food prices will disproportionately affect some segments of the population more than others. In particular, this will impact the urban poor who are estimated to spend 60%–80% of their income on food (Organization et al., 2017). Gender inequality exacerbates aspects of food access—particularly women in rural areas. As such, food systems need to provide access to food and livelihood security across all players of the food chain, or outside of the food chain.

The demand for food is constantly changing due to demographic shifts. Current estimates place the global population at 8.5 billion by 2030, of which the global middle class is expected to increase to almost half (4.9 billion) (Organization et al., 2017). While this is a welcome trend, certain aspects are of concern. The increase in urbanization places a huge demand on food systems, as two-thirds of the population is expected to reside in cities (Organization et al., 2017).

Eradicating poverty in all its forms is one of the greatest challenges that are yet to be fully addressed. Despite the strides in uplifting communities from poverty we have witnessed over the past decade, an estimated 17% of the global population live below the margin of poverty, while an estimated 10% live in extreme poverty (UNDP, 2020). As the income gap continues to widen, there is an increasing concern on shared access to prosperity worldwide.

An estimated 800 million people live below the global poverty line, while the richest 20% of the global population consume 86% of the world's resources (Organization et al., 2017). This rate of economic inequality is continuing to increase, highlighting slower growth and social cohesion globally, which further challenge the existing food system today. Moreover, as environmental challenges have resulted in increased failed harvests, more countries are relying on imports from higher productive countries, which more often have the technologies and capacities to invest in such technologies.

There are global hot spots of food insecurity, which are largely associated with geopolitical dynamics as well as impacts of climate change. This era is characterized by the highest level of population displacement recorded, with an estimated 65.3 million people displaced (Organization et al., 2017). Climate change has resulted in food production shocks that have negatively impacted food availability and accessibility across different parts of the world (Natalini et al., 2019). Consequently, amplifying the risk of food price spikes which aggravate global food insecurity and could also potentially lead to social upheavals (Natalini et al., 2019). Moreover, the rise in nationalist tendencies across Europe and the United States might also have a global impact on trade agreements and international collaboration around food systems (Organization et al., 2017).

While there is certainly a need to have policies at global and national levels around food systems or agricultural development, one can also look at the role the private sector can play in the development of food systems and bringing about prosperity. Here, we see the emergence of responsible business models (triple bottom line, circular business models, shared value models, and so on) as a way for the business organizations to contribute not just to economic benefits but also to social and environmental benefits. A popular framework is the creating shared value (CSV) framework by Porter and Kramer (2011), whose central premise is that the competitiveness of a company and the health of the communities around it are mutually dependent. Kramer (2016) discusses further the core idea of shared value stating that "we cannot solve problems such as poverty, food insecurity, and climate change without fully engaging corporations, and that corporations cannot continue to prosper unless they successfully address these issues." In a similar light of CSV, the cooperative models have been present in different arenas—from business, finance, housing, and so on.

2.5.2 Shared prosperity models

In the quest toward shared prosperity, preventing the formation of monopolies is perhaps the most important stride, and cooperatives offer an opportunity to achieve that. Cooperatives provide a structure of ownership and organizational goals that offer space for innovation and opportunities to maximize economies of scale (Navarra et al., n.d). They have played a key role in eradicating poverty, offering an opportunity to balance the demands of social and economic development, and as such are perceived as optimal solutions in emerging economies (Kwakyewah, 2016). As such, the year 2012 was declared as the International Year of Cooperatives in a bid to recognize and celebrate the role that these enterprises play in eradicating poverty and creating shared wealth (Kwakyewah, 2016).

They offer opportunities for improving agricultural practices and facilitating enhanced trade. They also offer pathways for their members to access affordable credit through mitigated risks and reduced transaction costs (Israel-Ayide, 2011). The formation of cooperatives can facilitate the adoption of agricultural innovations and the sharing of resources and information. Access to information is pivotal, as important information that could influence decision-making may not have been accessible for individual smallholder farmers but can be provided through the network of cooperatives.

In addition to sharing benefits, cooperatives are also beneficial for smallholders through their capacity to share losses and mitigate risks (Navarra et al., n.d). By diversifying the on-farm and off-farm activities, risks can be reduced. In addition, risks can be transferred from the individual to the organization, while providing access to supporting services such as loans and social security.

The cooperative model has many strengths and has particularly succeeded in New Zealand where agribusiness dominates the export sector (Woodford, 2008). Diversifying income streams can be seen through various mechanisms. Primarily, cooperatives can support their members in processing their products into various marketable forms and supporting them in market penetration (Israel-Ayide, 2011). The Fronterra model is the most successful cooperative model in New Zealand, controlling an estimated 90% of the dairy exports from New Zealand (Chiew, 2014). The strengths of the Amul model in India can be seen in its ability to diversify the portfolio of products, increase the efficiency of the supply chain, and offer innovation in branding and marketing (Arora, 2016). Amul's branding campaign recognized the value to its consumer base of incorporating nationalism to a recognized rural revolution and ultimately supporting farmers in gaining their economic freedom.

Moreover, cooperative models can also generate multiple revenue streams through off-farm diversification, such as tourism in Sekinchan and equipment rental in Afar (Box 2.6), thereby offering multiple services to their members to facilitate their pathway toward economic freedom. As a member owned structure that fosters social and economic advancement, successful models have played a key role in creating shared wealth and uplifting the community from poverty (Kwakyewah, 2016). However, cooperatives can also fail, and this has been reported, particularly in emerging economies, and is attributed to weak governance structures (Israel-Ayide, 2011).

While cooperatives control an estimated 40% of agricultural commodities in the European Union, it is estimated that a mere 5% of agricultural commodities in Africa are sold by cooperatives (Francesconi and Wouterse, 2017). This low market participation of cooperatives across Africa is largely attributed to low commercialization, rather than low numbers of cooperatives, which are abundant within Africa. The low commercialization is mostly due to disrupted cohesion within the cooperatives, which impair their capacity to integrate the value chain and provide a market platform for its members (Francesconi and Wouterse, 2017). It is reported that members of African cooperatives tend to sell their products directly to intermediaries, rather than rely on the collective marketing of their products through the cooperatives. This is one of the key advantages that a cooperative offers its members and is the main mechanism through which it increases revenue.

All the examples presented illustrate that cooperative model organizations in the food systems can be private sector led and contribute to overall prosperity. The cases also indicate that in addition to the cooperative business organization or cooperative of individuals, there is a role for a set of actors such as government agencies, business associations, farmers, education/training organizations, technology, and so on for the development of any system and in this case, food systems. The cases of Amul and Fonterra show the possibility for cooperative

BOX 2.6

Cooperative case studies from India, Malaysia, New Zealand, and Ethiopia

Amul, India: A quintessential example of private sector-led cooperative approach. This was a movement that started as a response to the exploitation of dairy farmers in Kaira district in the 1940s. At the time, dairy farmers in the Kaira district were selling milk at exceptionally low prices that disadvantaged them. Their drive led to the formation of a union that pasteurized milk, and as the union grew in numbers, output increased, which led to need for adoption of diversification routes. This included the processing of milk into various products, and the establishment of a supply chain spanning four distribution channels. Present in over 50 countries, the products are priced with attractive margins, and currently reach over a million retailers through an established network of 10,000 dealers (Das, 2014). This model is often referred to in the "White Revolution," which has helped India assume a role as one of the largest milk-producing nations.

Fronterra, New Zealand: This cooperative is owned by 10,500 New Zealand dairy farmers and has grown to employ 17,500 staff globally, with an estimated control of 90% of New Zealand's dairy exports (Chiew, 2014). It is currently the largest dairy exporter on a global scale and operates on a principle of mutuality, serving mutual interests of the owners (Woodford, 2008). A pivotal principle for the cooperative owners is a commitment toward sustainable practices and social responsibility, with the highest standards observed for maintaining milk quality and safety. In addition, Fronterra affords diversification opportunities through the production of dairy-based products such as butter, ghee, cheese, and so on.

Sekinchan, Malaysia: A successful rice cooperative in Malaysia, known for highly productive rice fields with above-average annual incomes for the farmers (Mek Zhin, 2012). In Sekinchan, the cooperative members follow a strict operating procedure—mini estate management systems—that ensures that all fields are managed simultaneously. In addition, the farm cluster has recently emerged as a tourist destination, drawing in a crowd of social media users attracted to its picturesque beauty. The cooperative has embraced this new market segment and developed suitable infrastructure to accommodate the visitors, thereby offering dual revenue streams for the cooperative members through rice farming and tourism.

Afar and Oromia Women Cooperatives, Ethiopia: This is a 5-year program that involves 10 cooperatives with 48−516 members engaged (UN Women, 2018). It supports smallholder women farmers by boosting sustainable agricultural practices through training on agricultural techniques and access to resources and equipment. Members of the cooperative have access to a jointly owned tractor to prepare their land, which is also rented out to nonmembers offering an additional income stream to the community. With increased yield and income, the cooperative also supports its members in financial management and saving programs.

organizations in the agri/food section to be large or global (with the associated challenges). The Malaysian case of the region is interesting in that the farmers developed two lines of revenues (from rice and tourism), and there are a series of actors involved in that system. The case from Ethiopia illustrates gender inclusivity and development through this cooperative model.

2.6 Partnership: breaking the silos of the people, planet, peace, prosperity, and partnership

The vision for sustainable food systems established by FAO identifies clear principles based on improving resource-use efficiency, livelihoods, and resilience (Grovermann et al., 2019). Sustainable food production requires a redesign of the food system—with an emphasis on complementarities across the pillars of sustainable development. From the earlier discussion of the four Ps, the development of sustainable food systems needs the involvement of multiple actors playing different roles, for example, government, industry, cooperatives, research institutes, civil society.

Such efforts will require nonconventional partnerships between sectors that did not conventionally converse with one another. It also necessitates the need for a multifunctional approach that balances economic, environmental, and social demands, while benefiting from technological advances (Zambon et al., 2019). Needless to say, emerging technologies and digitization will have lasting impacts on the food system.

Throughout the earlier sections, we have seen how sustainable food systems serve as a critical entry point to transform populations through eradicating poverty, improving nutritional status and health, and promoting equality and justice. This can be achieved through collective action, and agricultural innovation systems (AISs) are an important element in this transition toward sustainable food systems (Grovermann et al., 2019). Innovation systems can act as a pathway that brings together different actors in the transition to sustainable food systems.

AISs comprise three key components: research and education, business and enterprise, and bridging institutions (such as stakeholder platforms and rural advisory services) and enabling environment (such as governance, policies, and behavior) (Grovermann et al., 2019). It is a network of actors, supporting institutions, and the policies that support the development and adoption of products and services for economic and social good. This framework is all-encompassing and works toward integrating the entire production chain—from farming to processing, marketing and consumption—while carefully considering the synergies and challenges across the chain (Meynard et al., 2017). It is important to note that AIS does not only comprise technological innovations but also includes organizational, institutional, and policy-driven innovations (Meynard et al., 2017).

2.6.1 The role of digitization

Digitalization is the consideration of the impacts of digital technologies on societies and individuals (Fielke et al., 2019). Its impacts can be seen in how individuals interact with their environment, as well on a larger scale in the functioning of economies (Fielke et al., 2019). Large volumes of data are produced today, with an estimated 90% of the world's data created in the past 2 years and will grow exponentially. Connectivity is key to global access, particularly via Internet services, which has quadrupled from 2005 to 2015, with more than 40% of the global population connected (Organization et al., 2017). However, the digital divide has isolated some segments of the population.

The impacts of digitalization are wide spreading and have certainly extended toward agriculture and food systems today (Fielke et al., 2019). Such innovations, which have been dubbed "digital agriculture" and "smart farming," offer the opportunity to use limited resources more effectively, enhance economic efficiency across the supply chain, minimize waste production, and there are many more benefits that can be derived from the improved productivity. Digital technological innovations have a huge potential to advance food production across the entire chain, from the application of precision agricultural technologies that reduce costs associated with the input to the adoption of blockchain for enhancing supply chain efficiencies (Aiello et al., 2019). These changes are aligned with productivity gains and transformational changes in the production system that minimize both resource-use and labor demands (Fielke et al., 2019).

On the other end of the chain, the wider adoption of social media has played a key role in consumer awareness on aspects relating to health and the environment, such as health concerns linked to saturated fatty acids or GHG emissions and land use attributed to livestock production (Henchion et al., 2017), thereby influencing consumer demands and prompting a change in food consumption, particularly the move away from animal-based proteins toward plant-based proteins. Meanwhile, increased urbanization and economic development in low and middle-income countries have led to dietary transitions toward increased consumption of animal-based proteins (Henchion et al., 2017).

As the global rate of population growth predicts higher growth rate within low- and middle-income countries, the global consumption of animal-based products is expected to continue to increase. However, as consumers are increasingly connected and embracing sustainability values, digital technologies offer the opportunity to negotiate the values of enterprises and demand transparency from them.

2.7 Concluding remarks

Sustainable food systems take into consideration the complex relationships between the environmental, economic, and social components of sustainable development throughout the food value chain from preproduction to production, processing, distribution, and consumption including the outcomes of these activities and the various actors involved. For a more holistic framework of sustainability, peace and partnership (United Nations, 2015) are two the additional but critical components, which are now universally accepted. In this chapter, we explored in great detail the contribution of sustainable food systems toward achieving the SDGs through their contribution to the "5 Ps" (*people*, *planet*, *peace*, *prosperity*, and *partnerships*). Agriculture, which underpins our food systems, is the primary source of food and livelihoods for most people but our current food systems are a major cause for concern globally. Our current food production, processing, transportation, and consumption practices (including all the drivers, activities, actors, and outcomes) are leaving many people hungry, undernourished, and obese and rapidly destroying our planet and ourselves with it. On the other hand, socioeconomic benefits derived from global food systems are leaving many people poor and angry as they see the few rich and multinationals accumulate more wealth—a classic example of "poor developing the rich."

We have argued that for the world to achieve sustainable development, a shift to sustainable food systems is necessary in order to achieve not only food but also nutrition security and optimal health of *people*. Tackling the triple burden of malnutrition will require concerted efforts to address both the supply and demand side of food environment (defined by Swinburn et al. (2013) as the "collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people's food and beverage choices and nutritional status"). The acquisition and consumption of diverse diets that comprise a wide range of food groups are essential to tackle malnutrition and address the nutritional needs.

The challenge of tackling malnutrition, however, requires a concerted effort to address issues around availability, affordability, convenience, and consumer behavior and choices. To ensure optimal health and nutrition, we must address numerous drivers including individual and institutional factors that together will shift consumer behavior, fix both supply and demand side of the food environment including aspects related to food loss and waste, which account for up to 30% of the total global food production. Transforming our food system is also key to ending poverty, and it will help close the gender gap in agriculture, ensuring sustainable development and shared prosperity for all.

Our current food systems depend on a number of resources directly derived from the *planet*. Food production is the major user of natural resources including water (70% of freshwater) and energy (30% of global energy). Agriculture is also associated with land degradation and loss of biodiversity (which underpins our food) and contributes to and impacted by climate change. Transitioning to sustainable food systems will ensure not only food and nutrition security for all but will also protect our only planet and ecosystems from deteriorating further, enabling societies to build resilience in the face of threats posed by climate change.

To ensure inclusivity, *peace* and shared *prosperity*, we have addressed issues of equity and fairness including gender equality in food systems, which require special attention. Agriculture is the largest employer globally with most people in rural areas depending on it for their livelihoods. The playing field is however far from level. Inequalities exist around the world throughout the food value chain; from food production and distribution to consumption with major socioeconomic impacts, which are most felt by small-scale farmers and economically poor countries. Without shared prosperity, there is no peace; and sustainable development cannot be achieved in the absence of peace, justice, and equality; and without the governance structures that ensure that development benefits are shared fairly. We have also used shared prosperity models to highlight some success stories, but these are few and far between, as we continue to hear stories about land grabs, in Africa and South America sending more people deep into poverty.

Transition to sustainable food systems is only possible when all food system actors are actively involved. These include actors directly involved as part of the food system as well as those involved indirectly such as policymakers, nongovernmental organizations, the private sector, academia and research, the media, and so on The global food system is complex; to fix it, we need to build strategic *partnerships* and employ systems thinking across disciplinary boundaries, different government, private, regional, and international players. Each actor in these partnerships is an important part of a big jigsaw and are needed for the global food value chain to become more sustainable. Thereby, ensuring that all who are suffering from malnutrition have access to healthy and nutritious food, and farmers and farmworkers are fairly rewarded to ensure equity and fairness and that peace and prosperity for all are achieved within the confines of planetary boundaries -safeguarding our planet for future generation Emerging agricultural technologies and digitalization of the agrifood sector will have a lasting impact not only in terms of providing enabling and sustainable solutions but also in terms of bringing people from different disciplines and sectors, to work together to transform our food system for good.

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CHAPTER

3

Food security and nutrition in agro-food sustainability transitions

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3.1 Introduction

Food insecurity concerns are as old as humanity (Bureau and Swinnen, 2018; Candel and Biesbroek, 2018; Lang and Barling, 2012; Simon, 2012). The concept of "food security" has been expanded and has evolved over last decades (Committee on World Food Security, 2012; Gross et al., 2000; Lang and Barling, 2012; Shaw, 2007). It is nowadays clear that achieving food security implies more than just increasing food production; it also regards access to food (Dumont and Rosier, 1969; George, 1976; OECD, 2013; Pinstrup-Andersen, 2009; Sen, 1981). Indeed, the food security definition adopted at the World Food Summit 1996 (FAO, 1996) denoted a modification of focus from increasing food production to improving food access to address food insecurity (Ingram, 2011). Such a definition is still used widely and was reaffirmed in the Declaration of the World Summit on Food Security 2009 (FAO, 2009a,b), while adding reference to social accessibility to food: "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2009b). Food security has the following four dimensions (Committee on World Food Security, 2012; Ericksen, 2008; FAO et al., 2013; Simon, 2012; United Nations System High Level Task Force on Global Food Security, 2011): *food availability* (i.e., sufficient and constant food supply); *food access* (i.e., food affordability—having sufficient financial resources to buy food—and physical accessibility cf. food environments); *food utilization/use* (i.e., adequate utilization of food in line with good nutrition and care practices); and *stability* in the first three dimensions (availability, access, use). The most recent reports on the *State of Food Security and Nutrition in the World* (FAO et al., 2018, 2019) show that more people are undernourished in the world. Indeed, the world hunger trend reverted in 2015, after decades of continuous decline, remaining almost unchanged at a level above 10% over the previous 3 years. In the meantime, the number of hungry people has slowly increased. Therefore more than 820

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million people were still hungry in 2018 worldwide. However, it has been appraised that over two billion people do not have a good food security status, including 8% of population in North America and Europe, when considering both people affected by moderate levels of food insecurity and those suffering from hunger. Hunger is on the rise in Africa, Latin America, and Asia (FAO et al., 2019).

It is nowadays widely admitted that food security is critical to ensure good nutrition, and the two concepts are strongly interlinked and overlap (FAO, 2013, 2017). Nevertheless, this was not always the case; indeed, while food security was primarily addressed in relation to agriculture or from trade/market angles, malnutrition was mainly addressed as a problem relating to health. The focus of *nutrition security* is on the food consumption patterns and practices of individuals and/or within households and on the utilization of food by the human body (Committee on World Food Security, 2012), so that it is assimilated to utilization dimension of food security. Nutrition security refers to an appropriate nutritional status in terms of energy as well as macro- and micronutrients (e.g., proteins, vitamins, minerals) at all times and for all the members of a household. It adds to the concept of food security attention to sanitary environment, health services, and care practices (Committee on World Food Security, 2012). The State of Food Security and Nutrition in the World 2019 (FAO et al., 2019) highlights that the incidence of overweight and obesity is increasing worldwide; in 2016 about 40 million children under 5 years of age were overweight, whereas it was estimated that in 2018 around 2 billion adults were overweight.

Food security and nutrition security are usually considered jointly in two various ways, that is, food security and nutrition or food and nutrition security. In this context, *food and nutrition security* is considered as achieved when sufficient food is available (not only in terms of quantity but also of quality, sociocultural acceptability, and safety), accessible, and satisfactorily utilized for an active and healthy life, together with adequate sanitary environment, health, care, and education (Committee on World Food Security, 2012). Nevertheless, both ways of combining food security and nutrition security recognize that it is important to address the main nutrition-related issues to achieve food security while emphasizing the need for mainstreaming nutrition into policies and programs on food security (Committee on World Food Security, 2012; Pangaribowo et al., 2013). However, in the past the majority of food-related interventions and programmes/projects, particularly those relating to agriculture, seldom considered nutrition as a primary concern or objective (FAO, 2013; Pangaribowo et al., 2013; Ruel et al., 2018; UNSCN, 2016) and the concept of nutrition-sensitive agriculture emerged only recently (FAO, 2017; Ruel et al., 2018; Wesana et al., 2018).

The economic costs of malnutrition are shocking; it is estimated that undernutrition may decrease GDP by up to 11% in Asia and Africa, while obesity cost amounts to about two trillion USD annually on the global level, mainly due to the loss of economic productivity, plus direct health care costs (Dobbs et al., 2014). Therefore, attention has turned to the functioning, governance, and sustainability of food systems (Capone et al., 2019; Constance, 2018; Delaney et al., 2018; El Bilali, 2019b; Ingram, 2011; Marsden et al., 2018) to identify entry points for action to achieve food security and nutrition in the longterm. The High Level Panel of Experts on Food Security and Nutrition (HLPE, 2014: 29) puts that "A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes." Modern food systems, which are under unprecedented confluence of pressures (FAO, 2014a), failed in addressing malnutrition and food insecurity issues (FAO et al., 2014, 2015, 2017a,b, 2019; Foresight, 2011; Godfray et al., 2010a; WWW-UK, 2013).

Many scholars highlighted that food security dimensions are strongly linked to the elements, activities, and outputs of the food system (Beddington et al., 2012; Capone et al., 2016; Foresight, 2011; Garnett, 2014; Godfray et al., 2010b; HLPE, 2014). Therefore the significance as well as the need of adopting a systemic approach in dealing with food and nutrition security was stressed by the HLPE (2014) in its note on emerging and critical issues for food and nutrition security. The strong linkage between food system (cf. food system sustainability) and food security was further affirmed in the "sustainable food systems" definition issued by the HLPE (2014) in July 2014; "A sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised" (p. 31). The aforementioned definition clearly shows that the unsustainability of the food systems is a main driver of malnutrition and food insecurity. Therefore it comes no surprise that sustainability, food security, agriculture, and nutrition are more and more jointly addressed (El Bilali, 2019c; Lang, 2009). Contemporary debates highlighted food security as an integral part of food-related sustainability and vice-versa (Berry et al., 2015; Lang and Barling, 2012; Prosperi et al., 2014). Indeed, there is a growing agreement among scientists and scholars on the importance of sustainability for long-term food security (Berry et al., 2015; Garnett et al., 2013; Hanson, 2013; Lang and Barling, 2013; Pinstrup-Andersen and Herforth, 2008; Richardson, 2010; Smith and Gregory, 2013; UNEP, 2012a). In other words, sustainability (environmental, economic, and social) or sustainable agriculture and food systems are a precondition for food security in the long run (Berry et al., 2015; Capone et al., 2014; Gitz, 2015). Nevertheless, also food security is more and more considered as a condition for sustainability in the food arena, which means that there is a reciprocal relationship between food security and food sustainability (Berry et al., 2015; Capone et al., 2014). This is why food system sustainability and food security should be addressed together (El Bilali et al., 2018); Garnett (2014) identifies three perspectives (demand restraint, efficiency increase, and transformation of food system) to achieve both food system sustainability and sustainable food security. Similarly, the strong relations that connect sustainable food systems and good nutrition are underlined in different contexts (e.g., HLPE, 2017). Indeed, a more comprehensive and holistic understanding of the nexus between good nutrition and food-related sustainability has been integrated in the public health nutrition science (Ridgway et al., 2019) and the "new nutrition science" (Anonymous, 2005; Leitzmann and Cannon, 2005). Food systems sustainability is also considered in the Action Framework of the ICN2 (second International Conference on Nutrition) (UNSCN, 2017) and the Rome Declaration on Nutrition (FAO and WHO, 2014) as a prerequisite for improved nutrition.

Modern agro-food systems are at the midpoint of a nexus of global problems and issues (environmental, social, economic) and are crucial in addressing multiple sustainability challenges relating, among others, to food insecurity and malnutrition, climate change, population growth, resource scarcity, biodiversity loss, and ecosystem degradation (FAO, 2014a; Foresight, 2011; Garnett, 2014; Gladek et al., 2016; Godfray et al., 2010a,b; IPES-Food, 2015; Lang, 2009; Searchinger et al., 2013; Vermeulen et al., 2012; World Bank, 2015; WWW-UK, 2013) in the context of the 2030 Agenda on Sustainable Development (United Nations General Assembly, 2015). For that, food systems are central in the ongoing debate on trajectories toward sustainability. In this context, more and more attention is devoted to "transition" concept (Gazheli et al., 2012; Loorbach and Rotmans, 2010) and transition studies both in policy (European Environment Agency, 2016) and academia (Falcone, 2014; Köhler et al., 2019; Lachman, 2013; Markard et al., 2012; STRN, 2017). Furthermore, "transition" notion has gained a wider recognition in research on agriculture and food systems over the past decade (El Bilali, 2019b; El Bilali et al., 2018; Elzen et al., 2017; Hinrichs, 2014). The features of sustainability problems and challenges faced by humanity nowadays suggest the insufficiency of incremental changes and underline the need for radical, transformative, and systemic change (STRN, 2010). "Sustainability transition" notion (Markard et al., 2012) encompasses the ambition of transition toward sustainable systems (Lachman, 2013) such as agro-food systems. Sustainability transitions was defined by Markard et al. (2012) as "long-term, multi-dimensional and fundamental transformation processes through which established sociotechnical systems shift to more sustainable modes of production and consumption" (p. 956). Various frameworks are utilized in studies on transition (Lachman, 2013). El Bilali (2018b) reviews the most prominent heuristic frameworks in agro-food sustainability transitions research (i.e., multilevel perspective [MLP] on sociotechnical transitions, strategic niche management, transition management [TM], social practice approach [SPA], technological innovation systems). Costa (2013) suggests that food sustainability transitions refer to sociotechnical transformation processes that guide food practices to sustainability. El Bilali (2019b) puts recently that "Agro-food sustainability transitions refer to fundamental changes necessary to move toward sustainable agriculture and food systems" (p. 353). Spaargaren et al. (2013) add that food transitions refer to the processes of structural change that allows the emergence and diffusion of new modes and practices of food production and consumption that are more sustainable. These transformation processes regard the whole food chain, so from food production (cf. agriculture, including crop and animal production, fisheries/aquaculture), through processing, distribution, to consumption. A growing body of literature (El Bilali, 2019a; Maye and Duncan, 2017; Spaargaren et al., 2013) as well as an increasing number of initiatives in the food arena (e.g., UNEP, 2018) focus on transition to sustainable agro-food systems.

In line with the previous evidence, this chapter reviews research on agro-food sustainability transitions and analyzes whether and how it addresses food security and nutrition. In particular, this chapter describes the landscape of research on agro-food sustainability transitions in terms, among others, of topical focus, research themes, and bibliometrics (Section 3.2); sheds light on pathways for transition toward sustainable food systems (cf., efficiency increase, demand restraint, transformation of food system) that ensure food security and nutrition (Section 3.3); and analyzes whether and how research on agro-food sustainability transitions addresses food security and nutrition (Section 3.4).

3.2 Landscape of research on sustainability transitions in the agro-food system

The research field on agro-food sustainability transitions is rather young; El Bilali (2019b) argues that the first paper was published in 2003 (Wiskerke, 2003). The output of articles dealing with sustainability transitions is about 250 per year, and the total was close to 2000 in December 2016 (STRN, 2016). Therefore research dealing with sustainability transitions in the agro-food systems is still marginal in the mother field of sustainability transitions; in 2017 it represented only 13.2% of the published articles on sustainability transitions (El Bilali, 2019b).

Nonetheless, there is an upward trend as Markard et al. (2012) found that food was addressed only in 3% of articles on sustainability transitions indexed in Scopus, far behind energy (36% of all articles). The analysis of author affiliations suggests that research on agro-food sustainability transitions is mainly performed in European universities and research centers, especially Dutch and British ones (e.g., Wageningen University and Research, Open University, Erasmus University Rotterdam, Cardiff University). It also confirms the North–South gap (El Bilali, 2019b); sustainability transition studies as well as those addressing agro-food are still largely carried out in developed countries of the Global North (Lachman, 2013; Wieczorek, 2018).

3.2.1 Topical focus of and main themes in research on sustainability transitions in the agro-food systems

In his systematic review, El Bilali (2019b) found that, among the subsectors of agriculture (viz., crop production, fisheries/aquaculture, and animal production), fisheries and animal production are underserved in the research field dealing with agro-food sustainability transitions. Indeed, the majority of papers on agro-food sustainability transitions deal with crop production, but a growing number of articles address fisheries/aquaculture (Bush and Marschke, 2014; Lebel et al., 2008) or animal husbandry (Davidson et al., 2016; de Olde et al., 2017; Elzen and Bos, 2016; Elzen et al., 2011; Immink et al., 2013; van Mierlo et al., 2013). Some articles investigate transitions to sustainability in the context of the integration of crops and livestock (e.g., Moraine et al., 2016). As for crop production, prominent case studies include transitions toward organic agriculture (Ghaffari et al., 2015; Hauser and Lindtner, 2017; Vittersø and Tangeland, 2015) and agroecology (Cross and Ampt, 2017; Duru et al., 2014; El Bilali, 2019a; Gonzalez de Molina, 2013; Isgren and Ness, 2017; Levidow, 2015; Levidow et al., 2014; Meek, 2016; Miles et al., 2017; Pant, 2016). In a systematic review on the use of the MLP in studies on sustainability transitions in agriculture and food systems, El Bilali (2019d) found that among considered niches there were organic agriculture (Hauser and Lindtner, 2017; Seoane and Marín, 2017), agroecology (Duru et al., 2014; Isgren and Ness, 2017; Levidow et al., 2014; Pant, 2016), conservation agriculture (Vankeerberghen and Stassart, 2016), permaculture (Ingram, 2018), urban agriculture (Bell and Cerulli, 2012), integrated agriculture/farming (Vlahos et al., 2017), care farming (Hassink et al., 2013, 2014, 2018), alternative food networks (AFNs) (Audet et al., 2017; Bui et al., 2016; Crivits and Paredis, 2013; Lutz and Schachinger, 2013) (Table 3.1). Some articles deal with food systems in urban areas, especially in cities (Chiffoleau et al., 2016; Cohen and Ilieva, 2015; Gorissen et al., 2018; Moragues-Faus and Morgan, 2015), and urban/peri-urban farming (Gilioli et al., 2015).

Regarding the food chain stages, El Bilali (2019b) highlights that production (mainly crop production) is the most studied stage, but a number of articles deals with food procurement and distribution (Audet et al., 2017; Randelli and Rocchi, 2017; Stahlbrand, 2016), food processing (Long et al., 2018; Wiskerke, 2003), food consumption (Clear et al., 2015; Clear et al., 2016; Davies, 2014; Davies and Doyle, 2015; Dedeurwaerdere et al., 2017; Liu et al., 2016; O'Rourke and Lollo, 2015; Twine, 2015), and, even, food waste (Wonneck and Hobson, 2017). Some research articles embrace a food system approach and deal simultaneously with various food chain stages (Alrøe et al., 2017; Bui et al., 2016; Ely et al., 2016; Hinrichs, 2014; Hubeau et al., 2017; van Gameren et al., 2015; Zwartkruis et al., 2012). Other articles go even farther and address the water–energy–food nexus (Halbe et al., 2015) or the juncture between agriculture and water

TABLE 3.1 Examples of niches in the literature on sustainability transitions in agro-food systems using the multilevel perspective.

Paper	Analyzed niche	Country or region
Bell and Cerulli (2012)	Urban agriculture	United Kingdom
Bui et al. (2016)	Alternative food networks	France
Crivits and Paredis (2013)	Local food systems	Belgium
Davidson et al. (2016)	Alternative beef production	Canada
Duru et al. (2014)	Agroecology	France
Feyereisen et al. (2017)	Fair trade milk	Belgium
Hargreaves et al. (2013)	Organic agriculture	United Kingdom
Hassink et al. (2013)	Care farming	Netherlands
Hassink et al. (2018)		
Hassink et al. (2014)		
Hauser and Lindtner (2017)	Organic agriculture	Uganda
Ingram (2015)	Sustainable agriculture	Europe
Ingram (2018)	Permaculture	United Kingdom
Ingram et al. (2015)	Sustainable agriculture	Europe
Isgren and Ness (2017)	Agroecology	Uganda
Levidow et al. (2014)	Agroecology	Europe
Li et al. (2013)	Participatory maize breeding	China
Lutz and Schachinger (2013)	Local food networks	Austria
Nygaard and Bolwig (2018)	Jatropha biofuel	Ghana
Pant (2016)	Agroecology	Multi-country
Pitt and Jones (2016)	Food for Life catering mark	United Kingdom
Seoane and Marín (2017)	Organic apiculture	Argentina
Slingerland and Schut (2014)	Jatropha biofuel	Mozambique
Stahlbrand (2016)	Soil Association’s Food for Life	United Kingdom
Vankeerberghen and Stassart (2016)	Conservation agriculture	Belgium
Vlahos et al. (2017)	Integrated peach farming	Greece
Zwartkruis et al. (2018)	Agricultural nature conservation	Netherlands

Adapted from El Bilali, H., 2019d. The multi-level perspective in research on sustainability transitions in agriculture and food systems: a systematic review. Agriculture 9 (4), 74. doi:10.3390/agriculture9040074.

(Sixt et al., 2018) or energy (Hansen and Bjørkhaug, 2017; Nygaard and Bolwig, 2018; Partzsch, 2017; Raman and Mohr, 2014; Rodríguez Morales and Rodríguez López, 2017; Sutherland et al., 2015a).

Furthermore, El Bilali (2019b) carried out a systematic review of 111 papers that deal with sustainability transitions in agriculture and food systems and analyzed their alignment with the themes of the agenda elaborated by the Sustainability Transitions Research Network (STRN, 2017). He shows that the literature on sustainability transitions in agro-food systems is diverse and deals with all the themes of the research agenda (Table 3.2). However, authors do not treat all the research themes equally. Indeed, they focus largely on "governing and managing transitions" (24.5% of papers), "sustainable consumption" (20.7% of papers), and "power and politics in transitions" (18.9% of papers), while the themes of "modeling transitions" (10.8% of papers), "civil society, social movements and culture in transitions" (9.9% of papers), "role of industries and firms in transitions" (6.3% of papers) remain largely underserved. Many scholars highlighted that more attention should be paid to power and politics in the sustainability transitions research field (Hinrichs, 2014; Konefal, 2015; Lachman, 2013; Markard et al., 2012; Marsden, 2013; Scoones

TABLE 3.2 Themes of the research agenda of the Sustainability Transitions Research Network.

Research theme	Description of the research theme
Understanding transitions	This research theme addresses theoretical concepts and frameworks applied in sustainability transitions studies. Particularly, it focuses on approaches, methods, and perspectives to frame studies on transitions.
Governance, politics, and power	This research theme focuses on enhancing understanding of the role of governance processes in shaping transitions toward sustainability, with a focus on how power plays out and the politics involved in transition processes and journeys.
Implementation strategies for managing transitions	This research theme focuses on the assessment of the efficacy of instruments utilized in shaping sustainability transitions and on the design and testing of new tools and instruments to manage transition processes.
Civil society, social movements, and culture in transitions	This theme addresses the role of culture, civil society organizations, and social movements in defining the contours of transitions toward sustainability.
Role of industries and firms in transitions	This research theme deals with the role of industries and firms in the development of markets that foster and trigger sustainability transitions.
Transitions in practice and everyday life: sustainable consumption	This theme addresses consumption patterns and investigates how sustainability transitions induce changes in consumption habits and practices.
Geography of transitions	This research theme deals with the scalability and spatiality of transitions and studies why transitions take place in some contexts/places and not in others.
Modeling transitions	This theme aims to replicate the complexity of sociotechnical systems in models based, among others, on complex systems and evolutionary economics.

After Sustainability Transitions Research Network, 2010. A mission statement and research agenda for the Sustainability Transitions Research Network. Retrieved from <http://www.transitionsnetwork.org/files/STRN_research_agenda_20_August_2010%282%29.pdf> (accessed 10.02.17.).

et al., 2015). However, the systematic review performed by El Bilali (2019b) shows that these themes were well addressed in the research field. Conversely, research on the roles of agents (industries and firms; social movements, and the civil society) is still marginal and that confirms the critique that the research on sustainability transitions understates the role of agency (Lachman, 2013; Lawhon and Murphy, 2012; Shove and Walker, 2007; Smith et al., 2010; Stahlbrand, 2016). It is hard to explain that the role of the civil society and social movements is not adequately addressed in the research field, while grassroots and community initiatives constitute the backbone of AFNs (Gernert et al., 2018; Seyfang and Haxeltine, 2012). As for the geography of transitions, El Bilali (2019b) adds that "research on agro-food sustainability transitions, that draws predominantly upon single case studies, has largely failed so far to appropriately address the spatiality and scalability of transitions; that would be better addressed in comparative studies spanning across scales and spaces" (p. 361). The themes of research are not mutually exclusive. Indeed, many articles deal with different themes; for example, Davies (2014) deals simultaneously with governing transitions (cf. TM), transition modeling (see, participatory backcasting), and sustainable consumption (see, eating practices).

3.2.2 Research on sustainability transitions in agro-food systems: conceptual challenges

The dominant approaches in the scholarly literature on sustainability transitions often disregarded food systems and focused on energy and mobility systems. Some potential reasons for this apparent disconnection between food systems and sustainability transitions, as well as some specific challenges faced in research on food systems transitions, are presented hereafter.

Hinrichs (2014) suggests that the emergence of sustainability transitions out of research fields such as innovation, management, and technology and society created a programmatic and intellectual disposition against food systems. The inherent ecological basis of the food and agriculture systems may be less suitable to the technical-rationalist character of fields such as sustainable design, management, and engineering (Marsden, 2013).

Scholars working on sustainability in agriculture and food systems may have perceived technology innovation as part of the cause behind unsustainable systems rather than a solution strategy (Buttel, 2006). In this sense, research on agriculture and food systems has been rooted in different epistemologies (Hinrichs, 2014; Kirwan et al., 2013; Seyfang and Smith, 2007). This may have created a "conceptual disconnect" between these two research fields. However, more recent approaches in sustainability transitions have stressed the importance of changing social practices also (STRN, 2010) and increasingly acknowledge that transitions to sustainability in the agriculture and food sectors may not be primarily technology driven (Darnhofer, 2015) but social in nature as evidenced by grassroots innovations and green niches (Smith, 2006). This more recent, but rather late, development may explain ongoing collaboration between scholars from the two research fields of food systems and sustainability transitions.

In addition to this, for both energy and transport sectors, the elements of the system and the conduits that connect them are both obvious and easily traceable (Hinrichs, 2014; Levidow et al., 2014; Markard et al., 2012). In reviewing the literature, the challenges in applying the existing transition frameworks to food systems are evident (El Bilali, 2018b). In food systems, farm diversity, spatial configurations, and the multifunctionality of agriculture—touching several regimes—make it difficult to identify clear boundaries and transition processes (Sutherland et al., 2015b). In general, food system dynamics are difficult to grasp and comprehend (Peters and Pierre, 2014; Pothukuchi and Kaufman, 2000).

Context and geography may be another reason for the apparent disconnection between food systems and sustainability transitions. Markard et al. (2012) found that studies on sustainability transition cover mainly developments in the Netherlands, the United Kingdom, the United States, and Germany. As for food system transitions, it can be noted that transition and innovation theory has been mainly a European project (cf. the approach of sociotechnical transition emerged from a research program in the Netherlands), and much of the research on food systems (e.g., AFN) has been carried out in North America and Britain. Sustainability transition studies may thus be biased toward the scientific and technological issues encountered in the Global North. In the future, the geography of sustainability transitions may become an important research thread in sustainability transitions (Coenen and Truffer, 2012; Hansen and Coenen, 2015; Truffer et al., 2015). At the same time, Wiskerke (2009) observed that "the industrialization and globalization of the agri-food supply chain has disconnected food from its socio-cultural and physical territorial context." This underlines that food systems are dynamically evolving and that their boundaries are constantly shifting. It can, thus, be argued that food sustainability transitions can be fostered only by continuously updating the understanding of factors determining the erosion of food practices and diets (Bojorquez et al., 2015; Bottalico et al., 2016; Dernini, 2011) and the unsustainability of food systems (e.g., Gladek et al., 2016).

The normative challenge related to the definition of sustainability, identified as one of the main challenges faced in sustainability transition research and practice, is particularly pertinent to the food system. Again, interests and power play a role in identifying sustainability problems and selecting suitable approaches to address them (Smith and Stirling, 2008), as there are several competing paradigms (Elzen et al., 2017; Freibauer et al., 2011; Kitchen and Marsden, 2011; Levidow, 2011). Given the divergence in expected sustainability outcomes, there are inevitable questions raised in the food system, as in any other sociotechnical system, about whose sustainability is, or should be, prioritized (Smith and Stirling, 2010). In fact, food is a "wicked" arena with multiple conflicting demands and actors (Peters and Pierre, 2014; Tyfield, 2011). In this context, the three Ds (direction, diversity, and distribution) (Davies and Doyle, 2015; STEPS Centre, 2010), that shape the complex relation between innovation and sustainably, assume a particular relevance. Thus questions are raised in the food system not only about the desired direction of change to achieve a sustainable system but also about the diversity of options and the distribution of change benefits/impacts (El Bilali, 2018a, 2019a). This issue is exacerbated by the fact that the boundaries of the food system are inevitably subjective, and transition pathways are contested and inconclusive (Batie, 2008; Constance, 2018; Levin et al., 2012; Peters and Pierre, 2014; Shove and Walker, 2007).

Sutherland et al. (2015b) highlight the need for a territorial approach in agro-food systems, given the multiple linkages between niches and different sectors. Likewise, Lamine et al. (2019) argue that a "territorial approach" to agri-food system transitions "should allow actors and researchers to build a shared understanding of the transition processes within their shared territorial agrifood system, despite possibly different and diverging views" (p. 1). Transition studies concerning food have tended to concentrate on the local or community level examining, for example, the emergence of AFN but neglecting the wider system (Born and Purcell, 2006). Frequently, commentators have called for scaling up and out niches to achieve food system transitions (Hargreaves et al., 2013; Jowett and Dyer, 2012; McDonald et al., 2006; Millar and Connell, 2010; Pitt and Jones, 2016; Seyfang and Haxeltine, 2012). Many scholars have found that defining a niche requires careful consideration, and that actors/stakeholders in agro-food systems may be hybrid, thus playing roles in both regime and niche (El Bilali, 2019d; Elzen et al., 2011; Sutherland et al., 2015b).

Taking into account the complexity of sustainability transitions in food systems, the way forward for research and practice is not unambiguous. Therefore a deeper understanding of the different levels of the system—from personal stances (Vivero-Pol, 2017) and individual role transitions (e.g., Hauser et al., 2016) to landscape effects on niche-regime interactions (Bos and Grin, 2008; Elzen et al., 2011) will help to further develop the conceptual picture. Food system research and practice need to open up horizontally to other regimes and niches in related fields, and vertically to consumer sciences, while paying more attention to issues such as health, justice, and so on. Moreover, discourses on food are embedded in social and ethical values and political debates, so more attention will need to be paid to aspects of governance, politics, and power dynamics. It is also important to remember that the outcome of a transition is not necessarily sustainable; so environmental, sociocultural, economic, and health-nutritional impacts of transition on the food system—and its different elements (people, environment, processes, infrastructures, institutions) (HLPE, 2014)—should be analyzed.

3.3 Transition pathways toward sustainable agro-food systems ensuring food and nutrition security

Garnett (2014) suggests that there are three broad perspectives to achieve simultaneously food system sustainability and food security (Table 3.3). Referring to these perspectives, El Bilali et al. (2018) put that "Different strategies can be pursued to foster sustainability transitions in food systems: efficiency increase (e.g. sustainable intensification), demand restraint (e.g. sustainable diets) and food systems transformation (e.g. alternative food systems)."

Boosting agriculture and food production has been central in many initiatives and policies addressing food security. This approach found its operationalization in "sustainable intensification" (SI) concept that is nowadays broadly used in academia and policy to combine the imperative of producing more food for a growing world population with environmental sustainability. Indeed, the exploration of new paradigms to support the emerging agricultural intensification models led to the emergence of various qualifiers of intensification, for example, "sustainable intensification" (Garnett et al., 2013; Pretty et al., 2011; The Montpellier Panel, 2013), "eco-functional intensification" (Niggli et al., 2008), and "ecological intensification" (Chevassus-au-louis and Griffon, 2008; Tittonell, 2014). SI can be defined as "... producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services" (Pretty et al., 2011). It emphasizes the use of other factors (e.g., human capital, innovations, ecosystem services) beside agricultural production factors (water, land, labor) (CIRAD, 2016). FAO (2017) puts that "Sustainable intensification refers to strategies aimed at simultaneously improving productivity and environmental sustainability, which can be achieved through increasing species diversity in cropping systems or ecosystem-based strategies" (p. 15), thus relating intensification and diversification in agriculture. However, the Food Ethics Council (2012) highlights the absence of a significant discussion about the exact meaning and understanding of SI and, especially, its

TABLE 3.3 Perspectives to achieve food system sustainability and sustainable food security.

Perspective	Perspective focus	Rationale of the perspective	Food security in the perspective	Nutrition in the perspective
Efficiency	Changes in production	This perspective focuses on changes in production patterns. The onus in the efficiency mind-set is on producers to increase productivity and reduce environmental impacts through the use of appropriate, innovative technologies.	Food insecurity is considered a supply side challenge (cf. availability).	The perspective advocates argue that it is enough to make status quo healthier through, inter alia, product reformulation and information, crop biofortification for poor people.
Demand restraint	Changes in consumption	The demand restraint perspective focuses on reducing excessive consumption. It suggests that the problem lies with unsustainable consumption patterns of consumers and companies. Excessive and unsustainable consumption is considered as the leading cause of environmental problems.	The advocates of this perspective argue that there is nowadays enough food to feed everyone and that the challenge is resource-intensive diets and consumption patterns.	The perspective puts emphasis on food-related noncommunicable diseases and obesity while highlighting their associations with animal products.
Food system transformation	Changes in food system governance and functioning	The food system transformation perspective considers both production and consumption in terms of relations among food system actors. It interprets the food crisis as one of imbalance, inequality, or social injustice.	All four food security dimensions (availability, access, use, stability) are considered.	This perspective emphasizes diversity of indigenous foods and advocates for local production to be destined to local markets and consumption.

Adapted from Garnett, T., 2014. Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment? J. Clean. Prod. 73, 10−18. doi:10.1016/j.jclepro.2013.07.045.

effectiveness and usefulness as a strategy for sustainable agricultural development. Indeed, SI is nowadays used to accommodate different, sometimes diverging, types of agricultural development agendas: improved resilience to ecological shocks and climate change, increased capital, improved stakeholder participation, increased food security, improved livelihoods, women empowerment (Cafer and Qin, 2017; Carney, 1998; FAO, 2014b; Luloff et al., 2004; Marshall et al., 2007; Rockström et al., 2017; The Montpellier Panel, 2013).

Despite the changes in food security conceptualization, the term is still mainly used to refer to the need to increase food production (Dilley and Boudreau, 2001; Foley et al., 2011; Garnett et al., 2013; Gregory et al., 2002; Ingram, 2011), and the definition of food security lacks a food systems perspective (Blesh et al., 2019). FAO's projections show that a considerable production intensification might be needed in the future to meet the global increase in food demand (Bruinsma, 2011; FAO, 2012b). This is a possible scenario, but not necessarily a desired one as agriculture intensification may exacerbate negative environmental impacts and pressure on natural resources (e.g. water, land, biodiversity) (Foley et al., 2011). In spite of past success in growing agricultural production/output—thanks to intensification (cf. green revolution), modern tendencies accentuated worries regarding the continuity and stability of global food supply in the coming decades (Gladek et al., 2016). Indeed, meeting increasing global food demand implies enormous challenges for both the integrity of ecosystems and the sustainability of agriculture and food production (Tilman et al., 2002). The planetary boundaries and availability of inputs (e.g., phosphorus) represent rigid restrictions to the further expansion of food systems, which are the major contributors to planetary boundaries transgression and overextraction of biological resources (Campbell et al., 2017; Rockström et al., 2009; Steffen et al., 2015). The depletion of natural and nonrenewable resources is another limit to both agriculture expansion and intensification (Gladek et al., 2016). In this context, narrowing food system on productivity entails the risk of perpetuating political and scientific biases of the "green revolution," a paradigm that prioritized technical innovations over social ones (IPES-Food, 2015). This underlines that it is crucial to stress the importance of the "sustainable" in "sustainable intensification" as the negative impacts caused by agriculture on the environment (e.g., biodiversity loss, soil degradation, water pollution, greenhouse gas emissions, and climate change) are becoming a more pressing concern (Foresight, 2011; Gregory and Ingram, 2000; Nemecek et al., 2012; Williams et al., 2006).

All dimensions of the food system need a transition toward sustainability, including dietary patterns (IPES-Food 2015). *Sustainable diets* are key to health while ensuring food sustainability and long-term nutrition and food security (Berry et al., 2015). They are defined as "those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations" and they "are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources" (Burlingame and Dernini, 2012; FAO and Bioversity, 2010). Due to changes in lifestyles—caused, among others, by income increase and urbanization—dietary patterns are shifting toward higher use of animal-based and processed foods, and, consequently, higher resource demand (Aiking and de Boer, 2018; Lundqvist et al., 2008). This change in diets (that is referred to as "nutrition transition") has significant environmental and health implications (WWW-UK, 2013). Diets with high consumption of meat imply higher use of resources such as land, energy, and water (Gerbens-Leenes and Nonhebel, 2005; Pimentel and Pimentel, 2003; Willett et al., 2019). Furthermore, animal-based diets are related by many scholars to the increase of the incidence of different noncommunicable diseases (NCDs, e.g., diabetes) as well as obesity (Friends of the Eart, 2010; Pan et al., 2012; Popkin and Gordon-Larsen, 2004; Sinha et al., 2009; Swinburn et al., 2011; Willett et al., 2019). Therefore, White (2000) recommends transitioning from meat-based, high-calorie, and resource-intensive diets to plant-based/low-calorie ones in order to decrease food-related environmental impacts. The WWF (2016) puts that "a dietary shift in high-income countries – through consuming less animal protein – and reducing waste along the food chain could contribute significantly to producing enough food within the boundaries of one planet" (p. 14). Dietary shifts toward sustainable diets would slow down climate change and resources depletion, and decrease the incidence of NCDs (Aleksandrowicz et al., 2016). For that, the interest in sustainable diets is nowadays high in academia and among development agencies (American Dietetic Association et al., 2010; American Public Health Association, 2007; Burlingame and Dernini, 2012; DEFRA, 2009, 2011; FAO, 2012a; UNEP, 2012a,b, 2017; United Nations Standing Committee on Nutrition, 2012; Willett et al., 2019; WWF, 2016). Sustainable diets are put forward as an important strategy to foster the shift toward sustainable food consumption (El Bilali et al., 2018; Esnouf et al., 2011; Guyomard et al., 2012; Macdiarmid et al., 2011; Pluimers and Blonk, 2011; Sustainable Development Commission, 2009, 2011; Tukker et al., 2009). However, it is not that clear how such a shift can be achieved as diets intersect with numerous sectors (e.g., trade, agriculture) (Dibb, 2013), and the impact of policy measures on this shift is not yet satisfactorily explored (Jones et al., 2016; Lang and Barling, 2012). Indeed, although many indicators, metrics, and models were developed (e.g., Dernini et al., 2013, 2017), a coherent and integrated policy framework is still missing (Lang, 2014). However, Aiking and de Boer (2018) put that "a dietary transition from primarily animal towards plant protein products is required. Fortunately, new dietary guidelines are increasingly taking sustainability into account and the contours of a diet transition are slowly emerging."

It can be argued that the "food system transformation" perspective is by far the most political one among those analyzed by Garnett (2014). This perspective suggests that there is a need to change the whole structure and functioning of food systems, comprising interactions among their components (viz., environmental, social, and economic). Indeed, this perspective puts that achieving long-term food security requires changing the relations of power in the current food systems, which are more market driven than government driven (Lang et al., 2009; Lang and Barling, 2012). While the perspective is good at diagnosing food system failures and challenges, it finds difficult to develop concrete recommendations to foster action (Garnett, 2014). Moreover, the perspective recognizes the importance to decouple economic growth and human development from social exclusion and environmental degradation. This implies fundamental, radical changes in the global food system (from production to consumption), and WWF (2016) suggests different strategies to facilitate such a change: optimizing yield, promoting healthy consumption patterns, promoting agro-ecological practices, scaling up existing niche innovations, diversifying farming landscapes. The IPES-Food (2015) proposed 10 principles to steer transition toward sustainability in the agro-food systems; 5 out of these concern the types of analysis and knowledge that are needed to foster transition (e.g. transdisciplinary, holistic and systemic, independent, critically engaged, power-sensitive), whereas the other 5 regard values to shape sustainable food systems (e.g. sustainability, democracy and empowerment, social and technological innovation, diversity and resilience, adequate measurement/assessment). de Schutter (2014) stresses the need of food system democratization and puts that "Change can be expected neither from government action, nor from business initiatives alone, and grassroots innovations led by ordinary people have a limited impact. Only by connecting these different pathways for reform by food democracy can lasting food systems reform be achieved." While it is widely agreed that the current agro-food system needs an urgent, significant transformation/transition to sustainably feed the global population (Elzen et al., 2017; Gladek et al., 2016), the actors/stakeholders of the food system have diverse, divergent perspectives on agro-food sustainability challenges (e.g., Gaitán-Cremaschi et al., 2019), which makes it difficult to reach a genuine agreement and, even, a common understanding on the way forward (Garnett and Godfray, 2012; Garnett, 2014; Hulme, 2009). Indeed, as in the case of "sustainable intensification" discourse, there is no agreement on the meaning of "sustainability" (Béné et al., 2019; Gladek et al., 2016) that is contested and disputed because of the diversity of narratives and visions (Constance, 2018; Sonnino et al., 2016). Béné et al. (2019) argue that "the concept of sustainability, although widely used by all the different communities of practice, remains poorly defined, and applied in different ways and usually based on a relatively narrow interpretation" (p. 116). Therefore it is likely that agro-food system transition will not have one uncontested or obvious pathway but will reflect the diversity of contexts, places, approaches, options, and voices (Shove and Walker, 2007; STRN, 2010; van Dooren et al., 2018).

Alternative food systems (AFSs) are considered among concrete examples of how to bring about transformation in agro-food systems. In their analysis of what is alternative in alternative food systems, El Bilali et al. (2017) suggest using time, space, rules, and integration as narratives for sustainability transitions. They put that "the space attribute refers to the fact that AFSs tend to be more small-scaled, localized and horizontally integrated – examples include community-supported agriculture, farmers' markets, farm food outlets, box schemes, farm to school programs, or local public procurement initiatives" (p. 443). As for the time attribute, El Bilali et al. (2017) suggest that "emerging AFSs have put an emphasis on giving food enough time to grow, to be prepared with care and to be enjoyed in a social experience (e.g. the Slow Food Movement)" (p. 443). Regarding the integration attribute, the authors note that "a broad family of AFSs (e.g. organic and biodynamic agriculture) were inspired by the science of agroecology – thus attempting to increase the integration of agroecosystem elements" (p. 443). As for the fourth and last defining attribute, El Bilali et al. (2017) highlight that AFSs "attempt to change the rules and institutions that govern the interaction of value chain actors. Some initiatives (e.g. Fairtrade) have focused on the adaptation of trade linkages towards social justice and empowerment. Others, such as the food sovereignty movement promoted by La Via Campesina and local food cooperatives, are more radical and transformative" (p. 443). El Bilali et al. (2017) highlight that these attributes are not mutually exclusive and offer an exceptional opportunity for creating simple, compelling narratives to foster transition toward sustainable agro-food systems.

3.3.1 Perspectives to achieve food system sustainability and food security in the sustainability transitions literature

El Bilali (2019b) shows that articles focusing on consumption patterns and eating practices use a demand restraint perspective as per Garnett (2014). Nevertheless, El Bilali (2019b) highlights that the three perspectives are far from being mutually exclusive as they are oftentimes discussed in the same article. For example, Pant (2016) investigates the inconsistency of agroecology mainstreaming (cf., transformation of food system perspective) for intensifying crop production (cf., efficiency perspective). Similarly, Ely et al. (2016) relate intensification in agriculture (cf., efficiency perspective) and agroecology (cf., transformation of food system perspective) and link both pathways (viz., agricultural intensification and agroecology) to ongoing changes in the patterns of maize consumption (cf., demand restraint perspective). Moreover, Levidow (2015) points out existing conflicts between agroecology and the neo-productivist narrative in Europe that is expressed in "sustainable intensification." Davies (2014) links the productivist paradigm (cf. technology/ICT use) to urban food-eating practices and argues that technology advances and fixes in agriculture and food production (cf., efficiency perspective) are likely not enough to bring about radical transformations needed to achieve sustainable urban foodscapes. Likewise, the example of biofuels (Raman and Mohr, 2014) demonstrates that efficiency improvement does not always imply enhanced food security and agro-food sustainability, as the production of biofuel crops is not destined to human food consumption. Liu et al. (2016) highlight that efficient technologies of food production and agriculture (cf., efficiency perspective) are utilized as an entry point to transition to sustainable food consumption (cf., demand restraint perspective) in China. Other authors (Kuokkanen et al., 2017; Randelli and Rocchi, 2017) point out that it is vital to connect production and consumption, and suggest that only a balanced, interactive relationship between producers and consumers can bring about transition toward sustainability in the agro-food system. Therefore they highlight, tacitly, the need to embrace a "food system approach" in dealing with food security, nutrition, and sustainability in agriculture and food arenas.

Although many scholars who deal with sustainability transitions in the agro-food system make reference to the food system concept (Audet et al., 2017; Chiffoleau et al., 2016; Cohen and Ilieva, 2015; Crivits and Paredis, 2013; Ely et al., 2016; Jehlička and Smith, 2011; Jurgilevich et al., 2016; Kuokkanen et al., 2017; Lutz and Schachinger, 2013; Rossi, 2017; van Gameren et al., 2015; Vittersø and Tangeland, 2015); only a few articles embrace a food system approach (Chiffoleau et al., 2016; Ely et al., 2016; Kuokkanen et al., 2017; Marsden, 2013; van Gameren et al., 2015; Vittersø and Tangeland, 2015) that can be assimilated to the perspective on transformation of food system of Garnett (2014). Different alternative agriculture models—such as organic agriculture, permaculture, urban agriculture (El Bilali, 2019e)—promote systemic approaches to agro-ecosystems (El Bilali et al., 2017). Such AFSs adopt a holistic approach to agriculture and strive to link production and consumption (Edwards, 2019; Jarosz, 2008) by, inter alia, stimulating short food supply chains (e.g., Chiffoleau et al., 2016). They comprise food sovereignty and agroecology (Levidow, 2015; Lutz and Schachinger, 2013). Indeed, agroecology transformative potential is nowadays widely recognised (FAO, 2015, 2018; IAASTD, 2008; IPES-Food, 2016) and endorsed as a means for the redesign of agro-food systems, from field to plate (El Bilali, 2019a; Gliessman, 2015, 2016; Lamine and Dawson, 2018). Nowadays, the agro-ecological thinking and scholarship criticize the entire agro-food regime (i.e., not only intensive production systems but also resource-demanding consumption patterns as well as the unbalanced and unfair food system governance), instead of the earlier critique of agriculture industrialization through intensive production (Elzen et al., 2017; Gliessman and Engles, 2015; Holt-Giménez and Altieri, 2013; Lamine and Dawson, 2018).

3.4 Food security and nutrition in the scholarly literature on sustainability transitions in agro-food systems

El Bilali (2019b) analyzes, in a systematic review, whether and how food security and nutrition are addressed in 120 research papers that deal with agro-food sustainability transitions published between 2003 and 2018. He puts that "Food security and nutrition are still marginal topics in research on agro-food sustainability transitions. In fact, only 21.7% and 13.3% of articles on agro-food sustainability transitions address food security and nutrition, respectively. Meanwhile, only nine out of the 120 selected research articles address both food security and nutrition" (p. 566).

Most of the articles examined by El Bilali (2019b) make reference to "food security" in their introduction but only to underline sustainability transitions need, without any analysis of the impacts of transition to sustainable agro-food systems in terms of food security. Only some articles analyze the relationship between food sustainability transitions and food security. The perspectives adopted in these articles can be linked to the four food security pillars. Generally speaking, it is supposed that agro-food sustainability transition affects, either positively or negatively, food supply/availability (Ely et al., 2016; Jurgilevich et al., 2016; Kuokkanen et al., 2017; Levidow, 2015; Pant, 2014, 2016), food economic accessibility (Audet et al., 2017; Kuokkanen et al., 2017), food use (Davies, 2014; Ely et al., 2016; Jurgilevich et al., 2016), and/or stability in food system (Marsden, 2013). While the majority of the analyzed articles focuses on how transition to sustainability in the agro-food system affects the dimensions of food security, a few articles use a reverse approach and highlight that the quest for food security (particularly via agriculture intensification) can undermine undertakings to render agriculture and food systems more sustainable (e.g., Audet et al., 2017). Consequently, the discussion on the relationship between food system sustainability and food security oftentimes implies analyzing the role of innovation (not only technical/technological but also social/organizational one) and/or of alternative, niche models, and paradigms of agriculture and food systems, such as agroecology (Pant, 2014). Attempts to address food insecurity and malnutrition can also foster the introduction and/or further development of environmentally benign forms of agriculture such as organic farming (Hauser and Lindtner, 2017). What is highlighted in all the articles analyzed by El Bilali (2019b) is the strong connection between the sustainability of food systems (including agriculture production as well as consumption patterns and diets) and food security, which is in line with the sustainable food system definition suggested by the HLPE (2014). Moreover, transformations in the wider economy—for example, "bioeconomy" or "circular economy" (Jurgilevich et al., 2016; Levidow, 2015)—or in other economic sectors—such as energy (Raman and Mohr, 2014)—can have long-term effects in terms of food security. For example, Jurgilevich et al. (2016) analyze the effects of transition toward "circular economy" on sustainability in the agro-food system and food security. Raman and Mohr (2014) examine the implications of bioenergy development on food security and point out that biofuels generated food security-related concerns in the attempt to address climate change challenge. Anyway, the success of transition/transformation in any sociotechnical system depends on whether the niches succeed in addressing, in an effective and efficient way, the pressing problems leading to their emergence, for example, water pollution (Bui et al., 2016), food insecurity (Hauser and Lindtner, 2017; Järnberg et al., 2018), or food wastage (Jurgilevich et al., 2016). For instance, Jurgilevich et al. (2016) point out that "Sustainability and food security are enhanced in localized food systems through specializing in regional products ..." (p. 9). El Bilali (2019b) puts that "the case study approach that characterises sustainability transitions research, means that even papers that address the implications of transition in terms of food security and/or nutrition do so on a local scale, for a small number of people or a specific category of food chain actors (e.g. farmers, consumers). There is almost a complete lack of studies that address broader implications" (p. 569).

In general, all articles on transitions to sustainability in agro-food systems that deal with food consumption (Chiffoleau et al., 2016; Clear et al., 2016; Cohen and Ilieva, 2015; Dedeurwaerdere et al., 2017; Mylan et al., 2016; Rossi, 2017; Stahlbrand, 2016) address *nutrition*. There is, to a large extent, a correspondence between the nutrition focus and the transition framework that is used; nearly all articles that deal with food consumption make reference to SPA (Shove, 2003; Southerton et al., 2004; Warde, 2005). Moreover, articles adopting a food system approach (Jurgilevich et al., 2016; Kuokkanen et al., 2017) also deal with nutrition. Generally speaking, it is supposed that transition toward sustainable agro-food systems bring about changes, either radical or incremental, in dietary habits and food consumption patterns (Twine, 2015). Some authors put that concerns relating to health and nutrition (e.g., obesity, NCDs, food safety) offer a good entry point to foster transformation placing sustainability at the forefront of the global food system. For instance, Davidson et al. (2016) investigate the relationship between the risks relating to food safety (e.g., mad cow disease) and transition to sustainability in the production of beef in the Canadian province of Alberta and highlight that nutrition concerns can drive and shape journeys toward sustainability in AFNs. Lehikoinen and Salonen (2019) add that "The key to mainstream sustainable diets lies in the co-benefits - transition towards more sustainable diets . . . could be possible, if people felt that they can combine the selfish, hedonistic factors (e.g., health, weight loss) and altruistic factors (e.g., ecological benefits) in their everyday diets" (p. 1). Likewise, Godin and Sahakian (2018) put that "Time, mobility, and the relationships built around food and eating are forces to be reckoned with when considering possible transitions towards the normative goal of 'healthier and more sustainable diets'" (p. 123). Ferguson (2016) utilizes the case of the baking industry in Australia to underline trade-offs and tensions between the various dimensions and pillars of sustainability (viz., environmental, economic, social) during the process of transition. Vinnari and Vinnari (2014) highlight the main obstacles (e.g. social, economic, environmental, cultural) hampering transition toward plant-based diets.

Only a few papers deal simultaneously with both *food security and nutrition*; these are mainly those that embrace a food system approach or deal with food consumption practices and patterns (Chiffoleau et al., 2016; Clear et al., 2016; Cohen and Ilieva, 2015; Dedeurwaerdere et al., 2017; Kuokkanen et al., 2017; Liu et al., 2016; Mylan et al., 2016; Rossi, 2017; Stahlbrand, 2016). Indeed, all papers on agro-food sustainability transitions dealing with food utilization dimension of food security address aspects relating to food consumption as well and, consequently, nutrition (Chiffoleau et al., 2016; Clear et al., 2016; Cohen and Ilieva, 2015; Liu et al., 2016; Mylan et al., 2016; Rossi, 2017; Stahlbrand, 2016). For example, Liu et al. (2016) show that the emphasis in China is still put on enhancing the efficiency of agricultural production technology, whereas almost no attention is given to consumption habits, behavior and patterns, so that improvements in food production/agriculture are utilized as a means to enhance the sustainability of the entire food system. Consequently, Liu et al. (2016) suggest stressing the importance of considering functional relations between sustainable consumption and food production/provision. Focus on linkages between production and consumption is a common denominator of articles that deal simultaneously with nutrition and food security. Referring to the scholarly literature on sustainability transitions in agro-food systems, El Bilali (2019b) argues that "The disconnect between food security and nutrition scholarship, on the one hand, and agro-food sustainability transitions literature, on the other hand, might be due, inter alia, to the fact that while food security and nutrition are better assessed at household and individual level, respectively, research on agro-food sustainability transitions focuses on systemic change at larger scales. This disconnect may be further explained by the limited role of agency (i.e. the role of agents) in the sustainability transitions field, while food security and nutrition concepts are, by definition, 'people-centred'" (p. 569).

3.5 Conclusions

This chapter confirms the marginality of agro-food systems in the scholarly literature on sustainability transitions. Most of the literature on sustainability transitions in agriculture and food systems deals with crops and the production stage; other agriculture subsectors (e.g., livestock, fishery) and food chain stages (including processing and consumption) are underrepresented. Moreover, nutrition and food security are still marginal areas in articles addressing transitions to sustainability in the agro-food systems. It is assumed that agro-food sustainability transition would lead to increased food supply and availability, improved food economic accessibility (cf. food affordability), better food use, and more resilient agro-food systems. The processes of transition to sustainable food systems also entail changes and shifts in nutrition practices and diets. Although it is widely admitted that the perspective "food system transformation" should guide and shape sustainability transitions in agro-food systems, such a perspective is still seldom adopted by scholars in the research field. It can be argued that the scholarly literature on agro-food sustainability transitions is still more concerned with the "transition" component of "sustainability transitions" so that it overlooks sustainability impacts and outcomes such as food security and nutrition.

The Sustainable Development Goals (SDGs), adopted by the United Nations's Member States in September 2015, show that the transformation of the current agriculture and food systems toward sustainability is essential to achieve sustainable development. Such a transformation is also crucial to achieve sustainable food and nutrition security. Furthermore, understanding better the multifaceted relations between food system sustainability, food sustainability transitions, and food security is vital for an effective and efficient implementation of SDG 2 "Zero Hunger." In this respect, it is clear that any transition in agro-food systems (i.e., going beyond efficiency increase and demand restraint perspectives to a genuine transformation of food systems) should have a main goal to reach food and nutrition security for all. New approaches, tools, policies, and governance models are undoubtedly needed to make sure the achievement of food security and food sustainability in the face of growing pressures and burdens on agriculture and food systems (e.g., climate change). In particular, pathways to achieving Zero Hunger should center on participatory, place-based, adaptive, and context-specific solutions, while simultaneously attending ecological management and agroecosystem diversification, local institutional capacities, and quality local diets. They should integrate systems-based (e.g.socioecological/sociotechnical systems, complex adaptive systems) and territorial approaches as well as sustainable consumption and production rationale and combine strategies for SI of agricultural production, promotion of sustainable diets, and reduction of food wastage. In this context, research on sustainability transitions in agro-food systems can play a pivotal role in addressing the daunting challenges of food insecurity and malnutrition as well as the negative environmental, social, economic, and health impacts of agriculture and the agro-food sector.

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CHAPTER

4

Agri-food markets, trade, and food and nutrition security

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4.1 Introduction

The number of undernourished and/or malnourished people is growing worldwide (FAO et al., 2019). Indeed, after years of decline, the world hunger trend reverted in 2015 and the prevalence of undernourishment overcame 10%. In the meantime, the number of hungry people increased worldwide. Therefore there were more than 820 million hungry people worldwide in 2018. However, over 2 billion people worldwide suffer from hunger or are affected by moderate food insecurity levels. In particular, hunger is on the rise in Western Asia, all subregions of Africa (especially Sub-Saharan Africa), and Latin America (including the Caribbean). Furthermore, obesity/overweight has been increasing in all world regions; about 2 billion adults were overweight in 2018 (FAO et al., 2019). Moreover, the economic costs of malnutrition are increasing in a dramatic way; it is estimated that undernutrition can decrease the gross domestic product (GDP) of Asian and African countries by up to 11%, while the annual cost of obesity is estimated at USD 2 trillion, mainly due the loss of economic productivity, plus direct health care costs (Dobbs et al., 2014).

The definition of food security (FAO, 1996, 2009) represents a useful starting point in investigating the relations between food security and trade. It implies that food is *available* in sufficient quantities; all people have *access* to it (both physically and economically/financially) and use it properly. The fourth pillar of food security is the *stability* of these three dimensions, viz, availability, use, access over time (Brooks and Matthews, 2015). Trade and markets are among the main determinants of food (in)security (Erokhin, 2018). Indeed, Torreggiani et al. (2018) suggest that "achieving international food security requires improved understanding of how international trade networks connect countries around the world through the import–export flows of food commodities." Moreover, Erokhin (2017) puts that "Food security is increasingly influenced by multilateral trade systems and foreign trade

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policies implemented by national governments." The annual value of agri-food trade has increased about three times in the last decade, mainly in developing and emerging countries, thus attaining about USD 1.7 trillion (WTO, 2015). In this respect, the relation between trade, markets, food and nutrition security has attracted attention, among others, in the development agenda (cf. 2030 Agenda for Sustainable Development). Swinnen (2015) argues that "there have been major growth and structural changes in global agri-food value chains with major implications for international trade and food security." Target 2.c of the Sustainable Development Goal (SDG) 2 stresses that it is important to "Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility" (United Nations, 2015:16). In addition to solving the problem, and mitigating the consequences, of agri-food prices volatility, inclusive, effective, well-performing, and efficient agri-food markets are vital to address rural poverty and food insecurity/malnutrition. Enhancement of market functioning and governance can also foster the transition toward sustainable agriculture and food systems (FAO and INRA, 2016).

This chapter describes processes that affect the functioning of agri-food markets and determines their transformation pathway, linkages between trade and food and nutrition security as well as policies and practices shaping the contribution of agri-food markets and trade to food and nutrition security.

4.2 Agri-food markets and trade

Markets indicate places where farmers/producers sell their agri-food products and buy other inputs/products or services (IFAD, 2003). They can as well be considered as "collective devices that allow compromises to be reached, not only on the nature of goods to produce and distribute but also on the value to be given to them" (Callon and Muniesa, 2005:1229). Furthermore, the central purpose of markets is exchanging value taking into account rules that are specific to the context in which transactions take place and that depend on private contracts (e.g., buyer–seller contracts) as well as civic and social norms, public regulations and laws, and cultural customs (Callon, 1998). Therefore markets are strongly linked to value chains. In this context, *agricultural value chains* engage a wide range of actors that have various roles as nodes such as farmers/producers, importers, buyers, processors, brokers/marketers, exporters, and consumers (EuropeAid, 2011). Indeed, value chains include a system of competing for supply channels that connect the various actors and stakeholders (e.g., farmers, distributors, consumers) (Haggblade et al., 2012). Inclusive value chains make easier access of smallholders to markets (FAO and INRA, 2016). The participation of women in agri-food markets is still a challenge in many countries (Baden, 1998; World Bank et al., 2009). Women have an essential role in the agriculture and food industry despite their inadequate access to rural services and agricultural inputs (Ngomane and Sebola, 2016). Better access of rural women to agri-food markets can help to eradicate poverty, malnutrition, and food insecurity (Ngomane and Sebola, 2016).

To fully understand the dynamics of the transformation of agri-food markets, it is important to consider both drivers (dominants of change) and trends (directions of change) (Vermeulen et al., 2008). Different factors and drivers (e.g., policy transformation, urbanization, dietary transitions) have determined the deep change of agri-food markets. The ongoing transformation also affected their inclusiveness to the rural poor and women. Modern markets have different features that distinguish them from traditional ones: food quality and safety (cf. private standards) as main drivers of vertical value chain integration, product traceability, formalized contracts, specialized logistics and wholesale companies, centralized procurement, and increased interest in sustainable sourcing (Vermeulen et al., 2008). The economic liberalization brought about new opportunities and threats to the rural economy. Indeed, liberalization reduced the direct involvement of governments in agri-food markets, fostered the role of the private firms/companies, and reduced the regulations on foreign investment, thus increasing investment in the agri-food sector also in emerging and developing countries (Haggblade et al., 2007). Changes of agri-food markets worldwide are induced by the reduction of state interventions on agri-food markets, changes in consumers' preferences, the purchasing power of the population, as well as by the modernization of the food industry and retail. Globalization is one of the major processes inducing and shaping the transformation of agri-markets worldwide. This is mainly the consequence of agri-food trade liberalization (Narayanan and Gulati, 2002). Generally, trade plays a key role in stabilizing markets and reducing risks. The liberalization of agri-food trade affected all key actors in agri-food value chains. However, some scholars and practitioners expressed concerns regarding the impacts of agri-food trade openness and liberalization on small-scale producers, especially in developing countries, as many argue that only, or at least mainly, large commercial farmers (cf. agri-food corporations) get benefits from enhanced opportunities for export (Brooks and Matthews, 2015).

During the Uruguay Round, countries agreed to include agriculture in the General Agreement on Tariffs and Trade (GATT). One of the results of the Uruguay Round of multilateral trade negotiations under the GATT was the adoption of the Agreement on Agriculture as well as the Agreement on the Application of Sanitary and Phytosanitary Measures. The goal of the Agreement on Agriculture was to reform trade in agricultural products as well as national agricultural policies in order to ensure a fair market-oriented system of trade in agricultural products. The new rules have been set by the Agreement on Agriculture and referred to market access, domestic support to agriculture and export subsidies. Market access, domestic support to agriculture and export subsidies are "three pillars" of the Agreement on Agriculture. It also addressed nontariff barriers relating, among others, to the protection of environmental and food safety. Trade liberalization induced by the Uruguay Round Agreement on Agriculture affected the functioning and governance of agri-food markets worldwide. Changes in the prices of agri-food products and price volatility are the main parameters affected by the trade liberalization process. In this regard, Narayanan and Gulati (2002) put that "the direct impact of trade liberalisation is usually through change in prices of commodities that have been liberalized – or the impact effect. However, it also triggers a whole range of second-round effects through factor prices, income, investment, employment and demand linkages." Price transmission to domestic agri-food markets is influenced by the degree of integration in international agri-food markets; indeed, local conditions matter for price transmission and can be even more important than trade for some crops (Hatzenbuehler et al., 2017). Distefano et al. (2018) argue that "The expansion of global food markets brings benefits but also risks, such as shock transmission within the global network of trade relations." FAO (2011) adds that "measures such as import duties, export taxes, nontariff barriers or domestic policy such as support, all influence the extent to which price changes in domestic markets mirror those on international markets." Apart from trade liberalization, other factors such as production risks (e.g., pests, diseases, drought, floods) that are linked to the specificity of the agricultural sector and its strong relation with nature cause variation of agricultural outputs/ agri-food supply, which, in turn, can lead to price volatility on agri-food markets, especially that the production cycle is lengthy in agriculture, and agri-food supply is not able to quickly accommodate variations of agri-food prices (FAO et al., 2011).

Besides trade liberalization, according to Narayanan and Gulati (2002), factors driving the transformation of agri-food markets include intellectual property rights (IPRs) within the agreement on trade-related aspects of IPRs as well as sanitary and phytosanitary (SPS) measures (cf. plant/animal health, food safety, and quality standards), capital flows, and financial markets liberalization. Vermeulen et al. (2008) argue that "liberalization has contributed to the concentration of market power through expanding horizontal and vertical integration by market players." Global drivers (e.g., urbanization, income and purchasing power increase, technological changes, population growth, changing diets and consumption patterns) have significantly affected agri-food markets and food systems worldwide (Narayanan and Gulati, 2002; Reardon, 2000). For instance, "Urbanization in China ... carries significant implications for food security in China and the global food trade, given the role China plays on global food markets" (Hovhannisyan and Devadoss, 2018). Meanwhile, domestic factors shaping agri-food markets include national policies and regulations (e.g., agriculture, trade, taxation, consumer protection) (Vermeulen et al., 2008).

IFAD (2016) puts that the evolution of markets in the agri-food sector has been mainly induced by changes in policies and diets. Policy changes related to privatization and liberalization processes as well as increased public investments in market structures and infrastructure. In the meantime, dietary changes have been mainly induced by urbanization and income increases, especially in developing countries. Indeed, urbanization increased the consumption of quality processed products, particularly in emerging economies. Urbanization and the enhancement of the transport infrastructure have induced the spatial lengthening of agri-food value chains and their "deseasonalization." These changes have had far-reaching implications both in terms of the functioning and structure of agri-food markets and supply chains. Regarding structure, supply chains moved from local and short ones to geographically long ones. In the meantime, there has been an increase in the importance and power of modern, urban wholesale markets and logistics at the expense of traditional, rural traders (IFAD, 2016). Moreover, the domination of international/multinational agri-food corporations increased in modern, vertically-integrated agri-food value chains (McCullough et al., 2008). The liberalization and expansion of agri-food markets started with the proliferation of small- and medium-sized enterprises (SMEs) followed by vertical and horizontal concentration (especially in the retail sector, cf. "supermarket revolution"), consolidation, and "multinationalization" in all value chain segments (upstream, midstream, and downstream). These changes have deeply shaped the agri-food value chains, from production to distribution. As for the change in market functioning and conduct, it is worth highlighting the impacts of technology progress (e.g., ICTs), the proliferation of quality and safety standards, and diffusion of contracts used in market transactions (IFAD, 2016). Indeed, food safety and quality standards (Box 4.1) induced a deep transformation in the functioning and operation of value chains worldwide (Henson and Reardon, 2005).

4.3 Agri-food markets and food insecurity

The development of inclusive agri-food markets and value chains can critically contribute toward enhanced food security of chain actors and stakeholders (e.g., producers, consumers), especially in the countries of the Global South (EuropeAid, 2011). Many studies show that farmers' food security is positively affected by their participation in the markets (Montalbano

BOX 4.1

Trade and food safety standards

Food safety and quality standards and trade are central in ensuring universal access to safe and nutritious food for a growing population. In order to trade their products and access markets, producers must be able to meet specific standards, which assure consumers about the quality, safety, and, even, authenticity of agri-food products that they eat.

The *Codex Alimentarius* (CA) rules apply to the agreements of the World Trade Organization (WTO) on Sanitary and Phytosanitary measures (SPS Agreement) and Technical Barriers to Trade (TBT Agreement). Through the *Codex Alimentarius* Commission (CAC), established by FAO and WHO in 1963, national governments develop science-based food standards. Indeed, *CA* compiles internationally harmonized food standards and guidelines that aim to promote fair trade while protecting consumers' health. The WTO's Agreements on SPS and TBT rely on Codex standards.

The *SPS Agreement* specifies trade rules relating to food safety, animal health, and plant protection and ensures that these measures do not hinder or distort trade. It sets out a framework to achieve fair and smooth international trade while ensuring food safety. It covers, among others, requirements regarding production as well as inspection, certification, and labeling of final products. Besides the CAC (cf. food quality and safety standards), the SPS Agreement explicitly recognizes the rules of the International Plant Protection Convention for standards regarding plant health and the Office International des Épizooties/World Organization for Animal Health for standards dealing with animal health.

The members of the WTO also refer to CA standards within the *TBT Agreement*. While the SPS regards only measures dealing with food safety and health-related risks, the TBT deals with a wide range of product standards implemented by national governments to attain different policy objectives (e.g., human health protection, environment protection, consumer information). Therefore unless a measure regards food safety or plant/animal health, it falls in the framework of the TBT. The latter applies to trade of agricultural and industrial goods alike and deals with technical regulations (product characteristics, labeling requirements, packaging), standards (e.g., rules, guides), and conformity assessment procedures (e.g., procedures for inspection, registration, and accreditation).

Harmonization is a potent instrument to make trade more transparent, efficient, inclusive, and less expensive by decreasing, or completely eliminating, the requirement to conform to various standards and rules in numerous countries. The adoption of international food standards helps reducing the costs of trade by allowing smoother movement of agri-food products between markets. In fact, the internationally harmonized standards facilitate global trade, allow for economies of scale and promote efficiencies, aid national governments in designing science-based food safety measures, make easier and less costly conformity assessment procedures, and lower the prices of agri-food products for consumers.

Source: FAO and WTO (2017).

et al., 2018). Trade is particularly relevant in determining the status of food security of the rural households, especially the poor ones in case of natural disasters; Haggblade et al. (2017) put that "In the absence of trade, a drought that reduces domestic rainfed cereal production by 20% would compress already low calorie consumption of the rural poor by as much as 15%, four times as much as other household groups" (p. 27) in Sahelian West Africa. Jaud and Kukenova (2011) argued that agri-food value chains, comprising those of high-value export commodities (e.g., horticulture products), can contribute to rural development, thus increasing rural incomes and reducing rural poverty, and, consequently, contributing to food security attainment in rural areas. However, better market integration is not synonymous with a better food security status. For instance, in their analysis of the relation between the market of the ethanol (produced from maize) in the United States and the prices of maize in developing countries, Hao et al. (2017) found that "the U.S. ethanol market's impacts on maize prices in developing countries are heterogeneous and ... coastal countries are more susceptible to U.S. economic shocks. The estimates also suggest that countries more dependent on food imports and/or receiving U.S. food aid are at a higher risk of being affected by such shocks" (p. 629). Bekkers et al. (2017) argued that while market integration matters, income per capita remains the most important factor in elucidating the changes across countries in the pass-through of agri-food prices and suggested that "far greater price transmission of food price shocks at the commodity level to final consumers in low-income countries than in high-income countries. The implication is that future swings in world food prices will in particular jeopardize food security in poor countries. Trade policy measures of market integration also affect the pass through significantly" (p. 216). Anyway, markets and trade interact with all the four food security pillars/dimensions (FAO, 2015b, 2016) (Fig. 4.1).

The intersection between trade and food security dimensions/pillars is multifaceted, complex, and affected by a variety of factors that leads to big differences in experiences of single countries and makes it hard to identify a general, common pattern. Trade impacts food security through different channels, including income changes, food prices volatility, productivity gains, and changes in dietary diversity and quality (FAO, 2015b). Making reference to the indicators set on food security, the functioning of markets affects particularly the index of domestic food price (cf. access pillar) and

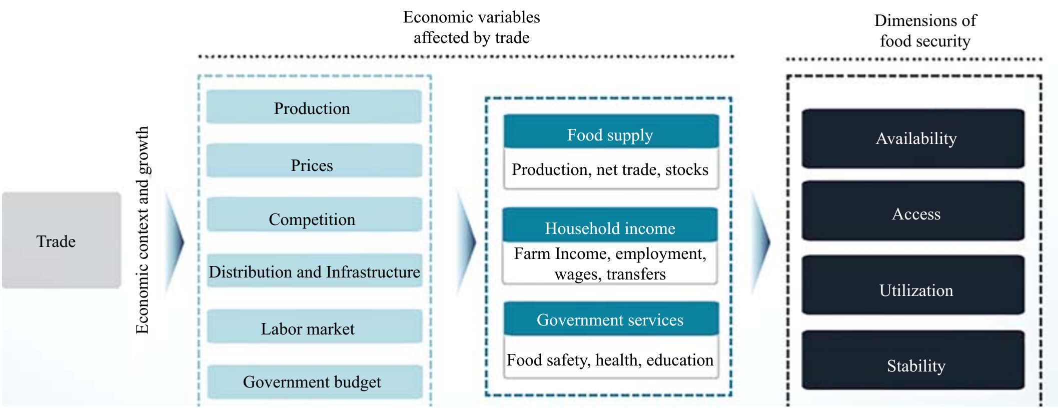

FIGURE 4.1 Interaction channels between food security dimensions and trade. *Source: Reproduced with permission from FAO, 2016. Trade & Food Security. Trade Policy Briefs No. 17. Rome.*

the volatility of domestic food prices (cf. stability pillar) (FAO et al., 2014). The relation between food security and the level of engagement in trade (especially of producers/farmers) is affected, among others, by the functioning and operation/business models of agri-food markets (FAO, 2015b). Trade can affect, either positively or negatively, each food security dimension (FAO, 2015b, 2016), thus impacting various economic and social parameters along with the time span (Table 4.1).

The functioning of agri-food markets as well as their contribution to food (in)security is also affected by the structure and governance of

TABLE 4.1 Possible effects (positive/negative) of trade on food security and its dimensions.

Dimension	Term	Potential positive effects	Potential negative effects
Availability	Short term	• Trade fosters agri-food imports, thus improving food quantity (food availability/supply) and food variety (cf. dietary diversity).	
	Medium to long term	• Specialization of farms and agri-food firms, thanks to trade, can increase agri-food production through gains in efficiency. • Agricultural productivity may be triggered, thanks to competition with foreign firms.	• High international prices can reduce domestic staple food supply by diverting domestic agri-food production to exports. • Domestic farmers that are unable to compete with international firms may curtail their production, thus decreasing domestic supply and reducing agricultural economy in rural areas.
Access	Short term	• Reducing border protection can decrease food prices, thus improving food affordability on domestic markets. • Trade can lead to a decrease in prices of imported agri-food products and agricultural inputs (e.g., fertilizers, seeds).	• Trade may increase prices on domestic markets of exportable agri-food products.
	Medium to long term	• Trade is likely to foster economic growth, thus increasing domestic incomes. • Macroeconomic advantages and benefits of greater trade (e.g., increase in the inflow of foreign direct investments (FDI), growth of export) foster job creation and employment (especially in the agri-food sector), hence economic growth.	• Wages and employment in import-sensitive sectors of the economy, as well as subsectors of agriculture, may decrease. • Uneven distribution of trade gains and benefits may take place by developing export-oriented crops (mainly by large companies) at the expense of the production of staple crops (mainly by smallholders).
Use	Short term	• More variety and diversity of foods, thanks to agri-food imports, can accommodate different preferences and make domestic diets more diverse and balanced.	• Risk of consumption of imported ready-to-use, highly processed, and cheap foods, which are rich in energy (cf. calories) and poor in nutrients.
	Medium to long term	• Rigorous international standards application may improve domestic food safety and quality levels.	• Risk of diversion of resources (land, water) from traditional, nutritionally superior foods to export commodities.

(*Continued*)

TABLE 4.1 (Continued)

Dimension	Term	Potential positive effects	Potential negative effects
Stability	Short term	• Reduction of price volatility and seasonality, thanks to imports. • Likelihood of food shortages because of domestic production risks mitigated by imports.	• Obligations stemming from international trade agreements can decrease the policy space that countries have to regulate their domestic agri-food markets and, consequently, their capacity to promptly react to crises and shocks. • Susceptibility and vulnerability to changing trade policies in exporting countries (e.g., export restrictions/bans).
	Medium to long term	• Global agri-food markets are more resilient and less prone to weather- or policy-related shocks than domestic markets.	• Economic sectors and agri-food value chains that are at earlier development stages can become more vulnerable to import surges and/or price shocks.

Modified from FAO, 2015a. Food and agriculture policy decision analysis (FAPDA). Retrieved September 15, 2016, from: <http://www.fao.org/in-action/fapda/background/policy-classification/en>; FAO, 2015b. The State of Agricultural Commodity Markets 2015–16. Trade and food security: achieving a better balance between national priorities and the collective good. Rome. Retrieved from: <http://www.fao.org/3/a-i5090e.pdf>.

nonfood markets such as the energy one. For instance, Taghizadeh-Hesary et al. (2019) investigated the nexus between energy and food security and concluded that "there is a linkage between energy and food security through price volatility. Since inflation in oil price is harmful for food security, it would be necessary to diversify the energy consumption in this sector, from too much reliance on fossil fuels to an optimal combination of renewable and nonrenewable energy resources that will be in favor of not only the energy security by also the food security" (p. 796). The authors also pointed out the significant impacts of biofuel prices on the prices of agri-food products so that "by increasing the demand for biofuel, there should be more concern about the global increase in agricultural commodities prices and endangering food security, especially in vulnerable economies" (p. 796).

4.4 Trade and nutrition

In recent years, with the polarization of ideological and political views regarding the strategies to achieve long-term food and nutrition security, trade has been considered as an opportunity by some scholars, policymakers, and practitioners and as a threat by others. The narrative "trade as an opportunity" supports trade openness as a means to enhance efficiencies and reduce distortions in global markets, while highlighting the negative impacts and costs of trade protection/protectionism (FAO, 2015b). For instance, Erokhin (2017) argued that trade protectionism jeopardizes the agri-food supply sustainability in Russia. Brown et al. (2017) suggested that trade restrictions can result in more harmful in the context of climate change; they put that "Trade can help us adapt to climate change, or not. If trade restrictions proliferate, double exposure to both a rapidly changing climate and volatile markets will likely jeopardize the food security of millions" (p. 154). The supporters of "trade as opportunity" narrative highlight the inefficiency of the concept of "food exceptionalism," that is, food is a good/commodity like any other one. Food security is perceived in this narrative to rely on the forces of market to reach more effective and efficient allocation of resources, and, hence, increasing the efficiency of agriculture, which, consecutively, fosters job creation/employment and economic growth (also in nonfarm sectors) with positive impacts on both food access and availability (FAO, 2015b). The narrative argues that trade liberalization in the context of globalization increases the competitiveness and productivity of the domestic agricultural sector, thus improving food security (e.g., Ospanov et al., 2015). Likewise, Hosoe (2016) put that the liberalization of agri-food trade can bring about a double dividend in Japan in terms of domestic food security and trade gains as liberalizing trade and, consequent, productivity shocks (especially for main crops such as rice, maize, wheat) can rise expected welfare while reducing welfare fluctuations in Japan. The supporters of "trade as opportunity" narrative admit that public policies and interventions have an important role to play, but they would restrict them to the correction of market failures if any (FAO, 2015b). Conversely, the "trade as threat" narrative is founded on the perception of agriculture as a provider of public goods, besides being an economic sector. The supporters of this narrative consider that markets only fail in providing public goods, hence "agriculture exceptionalism." The narrative promotes an alternative food security vision that emphasizes the "multifunctionality" of agriculture, leading to consideration of trade liberalization costs. This results in emphasizing smallholder farming, local farming, and food systems/networks. The narrative supporters call for a drastic decrease in the dependence on—not necessarily the total removal of—agri-food trade for achieving food security, hence for strengthening the role of the state in shaping national food policy or community food sovereignty (FAO, 2015b). Considering the food security—food self-sufficiency dichotomy, Erokhin (2017) suggested that restrictions in trade increase food self-sufficiency, but reduce food security. Also Mahendra and Zhong (2015), in their analysis of the relation between food security and trade in India and China, concluded that "Trade might provide cheap food to enhance access to food, the impact on domestic producers and the volatility in world market may lead to serious problems" (p. 641). Meanwhile, Clapp (2017) "takes a closer look at the concept of food self-sufficiency and makes the case that policy choice on this issue is far from a straightforward binary choice between the extremes of relying solely on homegrown food and a fully open trade policy for foodstuffs" (p. 88). In fact, each of the two narratives (*trade as opportunity* vs *trade as a threat*) provides solid arguments but also has some inconsistencies and weaknesses (Table 4.2). Therefore a crucial issue for decision-makers and planners across countries is how to enable agri-food trade to vitally contribute to food and nutrition security and domestic economic growth, while mitigating its negative impacts in order to compromise nobody's food security (Brooks and Matthews, 2015).

Some scholars connect trade, diets, and *dietary diversity*. El Bilali et al. (2017) explored the relationship between dietary diversity and biodiversity in the Mediterranean and pointed out that dietary diversity increased in most countries while there was an overall decrease of biological diversity in general and agro-biodiversity in particular. Therefore they argued that these opposing tendencies that affect Mediterranean dietary patterns can be due to rising affluence, with increasing food affordability, and trade liberalization. In fact, they put that "trade allows access to "external biodiversity." Anyway, it can be assumed that in a globalized economy, dietary diversity does not depend only on local biodiversity and that trade plays a very important role" (p. 6). FAO and WTO (2017) argued that "Trade is inextricably linked to food security, nutrition and food safety. Trade affects a wide number of economic and social variables, including market structures, the productivity and composition of agricultural output, the variety, quality and safety of food products, and the composition of diets" (p. 11). Likewise, Krishna Bahadur et al. (2018), referring to urban Cameroon and Ghana, pointed out that

TABLE 4.2 "Trade as an opportunity" and "trade as threat" narratives: main components and weaknesses.

Narrative	Main components of the narrative	Weaknesses of the narrative
Trade as an opportunity	• Refers to the "comparative advantage" classical theory to demonstrate that gains in production efficiency, thanks to open trade, improve domestic food supply, thus resulting in increasing food availability and affordability. • Refers to trade role as a "transmission belt" helping to smooth out domestic agri-food markets failures and dysfunctions (cf. food deficits/surpluses). • Refers to trade restrictions and their negative impacts on domestic, regional, and global food security.	Some assumptions behind the "comparative advantage" theory do not hold nowadays in the global economy: • Production factors (e.g., capital, labor) move quickly along agri-food value chains that are highly concentrated. • Externalities (e.g., environment-related footprints of intensive, industrial agriculture) are not internalized in the current agri-food prices. • "Competitive advantage" theory gives priority to efficiency gains versus social goals and to short-term benefits versus long-term structural transformation toward sustainability.
Trade as a threat	• Refers to "food sovereignty," that is, the right of states, communities, and individuals to shape and control their food systems. • It refers to the multiple functions of agriculture and stresses its function as a provider of public goods. • This refers to the risks of trade liberalization on agriculture.	• Evidence shows that food self-sufficiency cannot be achieved by some countries (e.g., resource-poor countries). • Trade protectionism may generate extraterritorial impacts, thus harming other countries' food security, especially in today's globalized economy. • Farmers' rights and sovereignty also include choosing to produce cash crops for export. • Challenges to make smallholder, small-scale agriculture meets growing food demand in an urbanized world. • Nutritional and distributional issues are not dealt with in an effective way in this narrative. • Without external competition, thanks to trade and market liberalization, the prices of agri-food products tend to be higher, thus impacting negatively food affordability for the poor. • Downfalls in domestic production may make supplies more volatile, especially in case of crises and shocks, if not timely compensated by trade.

Adapted from Clapp, J., 2015. Food security and international trade: unpacking disputed narratives. Background Paper Prepared for The State of Agricultural Commodity Markets 2015–16. FAO, Rome.

"households that live in 'primary' cities that are large and well integrated into global markets also enjoyed higher levels of dietary diversity" (p. 42) and suggested that "for well-off households, integration into global markets is probably preferable as such households enjoy more diverse diets" (p. 42). Also, Huang and Tian (2019) suggested that better food accessibility, through market development, contributed to improvements in diet quality in China and noted that "the impact of food accessibility on dietary quality is stronger for those not engaged in agriculture production" (p. 92). Weatherspoon et al. (2019) analyzed the relations between food security, food policy, and agri-food markets in Rwanda and put that "it is less clear if rural food markets are capable of supplying diverse and nutritious foods at affordable prices on a consistent basis, resulting in a lack of diversity and hence, low nutrient quality diets. Rwanda's next round of food security policies should focus on nutrition insecurity with special emphasis on the lack of protein, micronutrients and calories." Focusing on Russia, Erokhin (2017) argued that "trade protectionism challenges the sustainability of food supply by decreasing food availability and quality of food products, causes dietary changes and threatens the food security of the country." Likewise, Zanello et al. (2019) highlighted that "Market aspects become important for dietary diversity specifically in the lean season" in developing countries such as Afghanistan. Also, Abay and Hirvonen (2017) stressed the positive impact of households' access and nearness to markets on the nutritional status of children in Northern Ethiopia but pointed out the effect of seasonality. In fact, they put that "children located closer to food markets consume more diverse diets than those located farther away but the content of the diet varies across seasons" (p. 1414). Considering 26 countries of Central Asia and Eastern Europe (cf. ex-communist/socialist countries), Krivonos and Kuhn (2019) concluded that "trade barriers reduce variety of products available in domestic markets, in particular fruits and vegetables." However, some caution is needed as Rupa et al. (2019) showed that "alone, policies which encourage 'food market modernisation' are not enough to improve diet quality in urban Vietnam" (p. 499). This is corroborated by the findings of Umberger et al. (2015) who, in their analysis of the relation between overnutrition and supermarkets use in Indonesia, concluded that "there is mixed evidence for a negative effect of supermarkets on child nutrition" (p. 510). Moving from Asia to Africa (Kenya), Rischke et al. (2015) highlighted that "supermarket purchases increase the consumption of processed foods at the expense of unprocessed foods" (p. 9) and assumed that "supermarkets contribute to dietary changes commonly associated with the nutrition transition" (p. 9).

Numerous scholars analyzed the relation between food market development (especially that of supermarkets) and "nutrition transition" (Baker and Friel, 2016; Demmler et al., 2017; Kimenju et al., 2015; Rischke et al., 2015; Toiba et al., 2015). For instance, Baker and Friel (2016) noted the ongoing transformation in agri-food markets and highlighted that organized distribution (e.g., super- and hypermarkets, convenience stores) has become dominant as distribution channels in Asia, and there is an increase in "market trans nationalization" (i.e., market share held by transnational corporations of food and beverage with respect to domestic agri-food firms) and "market concentration" (i.e., market share of leading agri-food firms in each domestic market) but remarked that "market forces are likely to be significant but variable drivers of Asia's nutrition transition." Also, Toiba et al. (2015) focused on Asia and analyzed the link between "supermarket revolution" and diet transition as well as the related nutritional and health implications; they found that there is a "negative and significant relation between the share of food expenditure at modern food retailers and the healthiness of consumer food purchases" (p. 389). In their analysis of the association between the "food retail revolution" and diet and health in China, Zhou et al. (2015) argued that supermarkets induced changes in the patterns of processed food consumption, which can have impacts on the incidence of obesity among the Chinese population. Lobstein et al. (2015) noted the increase of the incidence of childhood overweight/obesity both worldwide (including in developing countries) and in the United States, and they suggested that in order to tackle this alarming pandemic "the governance of food supply and food markets should be improved and commercial activities subordinated to protect and promote children's health" (p. 2510). Anyway, it is clear that the relation between markets and nutrition is not straightforward, and for that Humphrey and Robinson (2015) argued that "a common set of constraints tends to inhibit markets from delivering nutrition and makes it difficult to reach populations at the 'bottom of the pyramid'" (p. 59) and suggested a need for renewing focus on informal markets targeting the poor.

Markets and trade are also an important component of the "food environment" (e.g., Herforth and Ahmed, 2015) that has been recently studied for its effects on overweight and obesity, especially among children and teenagers. For instance, Baker et al. (2016) argued that "Free trade agreements (FTAs) can affect food environments and non-communicable disease risks through altering the availability of highly-processed foods" and added that "The FTA may have resulted in … soft-drink production and also contributed to the diversification of soft drinks produced and sold in Peru with some positive (stagnated carbonates and increased bottled water) and some negative (increased juice and sports & energy drinks) implications for nutrition." However, some pieces of research show that the absence of supermarkets in some areas leads to the so-called food deserts (Lu and Qiu, 2015; Sadler, 2016), which are considered detrimental for food security and nutrition. For instance, Sadler (2016) found that moving a farmers' market to a prominent, central location in Flint (Michigan, United States) enhanced accessibility to healthy food by low-income and mobility-constrained residents in isolated food deserts. Lu and Qiu (2015) identified two food deserts in Calgary (Canada) and argued that "farmers' markets provide surrounding neighborhoods with significant benefits" (p. 267) but "the overall alleviating effects on the lack of access to healthy food are limited" (p. 267).

All in all, it seems that the effects of markets and trade on food security and nutrition are mixed, and FAO (2015a,b) highlighted that "Trade itself is neither an inherent threat to nor a panacea for improved food security and nutrition, but it poses challenges and risks that need to be considered in policy decision-making. General and unqualified assertions about trade 'hurting' or 'helping' food security should be considered with caution, and the nature of the variables and links behind these assertions must be scrutinized carefully" (p. 17).

4.5 Policies for fostering the contribution of agri-food markets and trade to food and nutrition security

Global markets of agri-food products have been expanding quickly, but the trade pattern varies meaningfully across countries/regions and for the different commodities. The main food production/agriculture and food demand drivers—comprising *trade and related policies*, that is, all policy instruments that affect trade such as border protection or domestic market interventions (Table 4.3)—shape these patterns in different ways (FAO, 2015b). All over the world, states and governments influence and regulate

TABLE 4.3 Types of trade and related policy instruments.

Type of policy	Examples
Trade-oriented policies	Trade regulation and border measures Macroeconomic policy measures
Producer-oriented policies	Support and incentives to producers (e.g., input subsidies, production subsidies) Market management measures (e.g., fixing minimum and maximum prices for agri-food products such as food staples)
Consumer-oriented policies	Market management measures (e.g., price controls, food stocks) Social protection measures and safety nets (e.g., food-for-work programs, food subsidies, school feeding programs, cash transfers to the poor) Nutritional assistance measures (e.g., supplementation, food fortification including biofortification)

Adapted from FAO, 2015a. Food and agriculture policy decision analysis (FAPDA). Retrieved September 15, 2016, from: <http://www.fao.org/in-action/fapda/background/policy-classification/en>.

agro-food production and food market. However, the ways and instruments of such regulation depend on the goals to be achieved (Battalova and Kundakchyan, 2017). In particular, policy instruments differ among food-exporting and food-importing countries (Gouel, 2016). Different factors should be considered while formulating agri-food trade policies and interventions to enhance food security; these include the geography of food insecurity, the functioning of agri-food markets, the capability of farmers to meet changing incentives that trade can bring about, or to address challenges that it might imply (FAO, 2015b). Therefore Timmer (2015) put that "poverty and hunger are different in every country, so the manner of coping with the challenges of ending hunger and keeping it at bay will depend on equally country-specific analysis, governance, and solutions" and this implies that "Ending hunger requires that each society find the right balance of market forces and government interventions to drive a process of economic growth that reaches the poor and ensures that food supplies are ready, and reliable, available and accessible to even the poorest households." Furthermore, the suitability of alternative options of trade policy in each country depends largely on the role that the agriculture sector plays within the longer term processes of domestic economy transformation (FAO, 2015b). While some countries tend to put emphasis on short-term policies to offset the immediate effects of high prices of food (cf. food price spikes), Legwegoh and Fraser (2017) stressed that it is essential to focus on long-term strategies and public investments (e.g., improved farm-to-market roads, support to agricultural sector) to achieve sustainable food security.

Agri-food markets, which are part of wider production systems, are shaped by various *general policies* (e.g., tax, competition, employment, technology, welfare, SMEs) that affect transaction costs, conditions of investment, availability of production factors, inputs, and so on. These general policies influence the attitude and behavior of food chain actors, which, in turn, determines value chain inclusiveness. Furthermore, there are also targeted policies and programs that relate to matching (e.g., supplier exhibitions, subcontracting exchange schemes), supporting spill-overs from lead agri-food companies and firms (e.g., grant schemes for initiatives led by the private sector), easier access to finance (cf. credit access), and fostering inclusive social standards (e.g., labor standards). Nonetheless, also policy coherence and coordination affect the inclusiveness of agri-food markets; policies and their specific instruments have synergies and/or trade-offs. So, it is vital to take into account the interfaces and interactions (synergies, trade-offs) among policy interventions (Altenburg, 2007). Indeed, referring to South Africa, Thow et al. (2018) highlighted that "food supply is governed by a number of different policy sectors, and policy incoherence can occur between government action to promote a healthy food supply and objectives for economic liberalization" (p. 1105) and put that "Opportunities to strengthen policy coherence across the food supply for food security and nutrition include specific changes to economic policy relating to the food supply that achieve both food security/nutrition and economic objectives; creating links between producers and consumers, through markets and fiscal incentives that make healthy/fresh foods more accessible and affordable" (p. 1105). Gouel et al. (2016) put that "India has pursued an active food security policy for many years by using a combination of trade policy interventions, public distribution of food staples, and assistance to farmers through minimum support prices defended by public stocks" (p. 811).

Beyond national policies, markets and trade are affected by multilateral and international agreements such as those within the WTO. Indeed, FAO (2015b) put that "Trade and food security concerns can be better articulated in the multilateral trading system through improvements to the WTO's Agreement on Agriculture. However, the right balance needs to be struck between the benefits of collective action brought through disciplines on the use of trade policy, and the policy space required by developing countries, the identification of which needs to be informed by specific country-level needs" (p. 2). Erokhin (2018) put that "Food security is increasingly influenced by foreign trade policies implemented by national governments" (p. 28) and called for paying more attention to trade policies in order to avoid the negative effects of food trade distortions by balancing liberalization and trade protection policies to achieve sustainable food security. Furthermore, multinational and international development programs focusing on food security and nutrition, for example, the "New Alliance for Food Security and Nutrition" of the G7 (Brooks, 2016), also have implications in terms not only of the functioning of agri-food markets but also of global food trade.

FAO (2011) argued that "A food security strategy that relies on a combination of increased productivity and general openness to trade will be more effective than a strategy that relies primarily on the closure of borders." However, trade can help to achieve food security but it can also make vulnerable importing countries, even rich countries such as Qatar (Box 4.2), in the case of shocks and unexpected events. The food price spikes of 2007–08 served as an alarm for Qatar and other

BOX 4.2

Importance of trade in achieving food security in developed, resource-poor countries: case of Qatar

Qatar is a small country located in the Persian Gulf covering an area of approximately 11,437 km^2, with a population of 2.7 million. The territory is surrounded by Gulf waters with a sole land border with Saudi Arabia. Qatar has the third largest global gas reserves, after Iran and Russia. Enormous hydrocarbons reserves, with respect to a modest population, made Qatar the richest world country with GDP per capita at USD 120,000 in purchasing power parity terms in 2016.

However, food security is still an important challenge in Qatar. Historically, food production in Qatar and in the Gulf Region was based mostly on traditional fishing, Bedouin animal production (e.g., camels), date farming, and small-scale horticulture. Since the 1970s, Qatar relies heavily on food imports to sustain its booming population. Due to its robust fiscal position, Qatar, like the other GCC countries, has been more resilient to price volatility than other food-importing countries (Efron et al., 2018) and able to fill the gap in domestic agri-food production (Ismail, 2015). In 2018 Qatar was ranked 1st in the Arab world and 22nd globally in the Global Food Security Index elaborated by The Economist Intelligence Unit (2018).

In 2007–08, and as a consequence of the global food prices spikes and food riots in many countries, the Qatari government adopted three important strategies to offset fluctuations in global supply: increasing local agri-food production to achieve the highest possible self-sufficiency level, foreign agro-investments, and long-term arrangements for food imports (Mustafa, 2017). In 2008 the government adopted the ambitious Qatar National Food Security Program to increase food self-sufficiency in the country from 10% to 70% by 2023 (Ismail, 2015). However, the financial and environmental costs, expected to outweigh the cost of importing food, forced the government to abandon the plan and concentrate on foreign agro-investments and long-term food import arrangements (Ismail, 2015; Mustafa, 2017). In 2008, Hassad Food, the agricultural arm of the sovereign wealth fund of Qatar, was established in order to contribute to food security in Qatar through foreign agro-investments (McSparren

BOX 4.2 (*cont'd*)

et al., 2017). Since then, Hassad Food acquired agricultural lands in Australia and Africa, among other places, or invested in foreign agri-food businesses and companies, and exported food to Qatar (Salacanin, 2013) so that the country can have control over the whole food supply chain.

Notwithstanding, Qatar still imports more than 90% of its food, and the future of food security in the country is challenged. First, food prices are likely to continue being volatile in the coming years/decades, and this can cause export bans/restrictions by some countries with, consequent, speculation (World Bank, 2011). Second, since nearly all food imports come through the Saudi border and Hormuz Strait, the geopolitical instability of the region threatens the security of Qatar's food supply (McSparren et al., 2017). Any disruptions to food shipments due to conflicts in the Hormuz Strait could have strong negative consequences on Qatar's food security (Ismail, 2015). Furthermore, denied food supplies from Saudi Arabia following the blockade of June 2017 have highlighted the high reliance of Qatar on agri-food imports. Until the blockade, Saudi Arabia and UAE accounted for 27.4% of Qatar's total value of food products. Meanwhile, about 80% of Qatar's food imports passed through a neighboring country, with 40% coming through the Saudi border and 60% of dairy products imported by Qatar coming from Saudi Arabia and the UAE. In response to the blockade, Qatar has adopted a range of strategies to ensure its food security. Indeed, Qatar arranged alternative trading routes and food supply chain with new partners, for example, Iran, Oman, Turkey, and Pakistan (Bouoiyour and Selmi, 2019; Efron et al., 2018; Miniaoui et al., 2018). Qatar also expanded its new Hamad port to prepare for additional shipping (Kumar, 2018). Nevertheless, the blockade showed the drawbacks of food policies that make food security too dependent on food imports and highlighted the urgency to boost domestic agriculture and agri-food production in Qatar (Ben Hassen and El Bilali, 2019; Miniaoui et al., 2018).

neighboring countries of the Gulf Cooperation Council (GCC) regarding their vulnerability to food prices and trade, as over 30 countries (e.g., Argentina, Russia, India, Vietnam) imposed export restrictions (Bailey and Willoughby, 2013). This led Gulf countries to think that they "now face the specter that someday they might not be able to secure enough food imports at any price even if their pockets are lined with petrodollars. This has reinforced the impression that food security is too important to be left to markets" (Woertz, 2011). Indeed, "greater participation in global trade is an inevitable part of most countries' national trade strategies. However, the process of opening to trade, and its consequences, will need to be appropriately managed if trade is to work in favor of improved food security outcomes" (FAO, 2015a,b:2).

While much of the literature deals with national food policies regarding agri-food markets and trade, evidence shows that *local policies and regulations* are also relevant in achieving food security and good nutrition. For instance, Zhong et al. (2019) referring to Nanjing city (Jiangsu province, China) identified "various food security policies and regulations implemented by the Nanjing municipal government, such as the 'vegetable basket' policy, the 'crawling peg' policy in urban planning, the financial supports for upgrading wet market facilities and reducing rental fees, and the regulations on the retailing of fresh produce in supermarkets" (p. 1071) and added that these policies ensure a fairly easy and equitable access to safe, healthy food for the inhabitants of Nanjing city.

Last but not least, it should be pointed out that the relationship between food security and trade is reciprocal; on the one hand, trade policy affects national food security but, on the other hand, policies adopted by a country to achieve its food security also affect global food trade. The latter is clear in the case of Russia, where Wegren et al. (2016) put that "The largest impact of food security has been on food trade. Food security policy has brought food to the forefront as an instrument of foreign policy. Food trade is politicized, witnessed by the food embargo against the West and food import bans against Turkey and Ukraine" (p. 671).

4.6 Conclusions

Evidence shows that agri-food markets and trade have far-reaching impacts on food security and nutrition. For that, achieving long-term and sustainable food and nutrition security implies a good understanding of the dynamics and trends of global agri-food trade as well as the functioning of domestic/national and local agri-food markets. Different global and domestic drivers have brought about profound changes in both the functioning and organization of agri-food markets. The transformation of food-related markets and trade implies opportunities and challenges with regard to food security and nutrition. The functioning of modern agri-food markets affects all the dimensions/pillars of food security, but with more relevance in shaping market access by farmers/producers and access of consumers to sufficient, nutritious, and safe food, which is affected by food prices and their volatility. Global trade can also have a vital role in ensuring the adaptation of the global agri-food system to climate change. So, enhancing the functioning and governance of agri-food markets and trade rules is essential to attain long-term, universal food and nutrition security. The eradication of all forms of malnutrition (undernutrition or hunger, micronutrient deficiencies or "hidden hunger," and obesity/overweight) by 2030 is an important SDG in the framework of the transformative 2030 Agenda, and trade is widely recognized as a means to achieving this key goal. However, it is essential to make sure that agri-food trade expansion works for eradicating hunger, malnutrition, and food insecurity and not against these targets. Indeed, agri-food trade should be managed in such a way to effectively exploit the advantages of widened access to agri-food markets while reducing the risks and drawbacks associated with agri-food markets volatility and international competition, especially for smallholders in developing countries. This is central in the negotiations to change the current global agreements on agricultural trade. It is also important to pay more attention to the effects of market development and "supermarketization" as well as trade openness on nutrition outcomes especially regarding the obesity pandemic determined by "nutrition transition." Therefore the challenge ahead is to develop competitive, accessible, well-performing, inclusive, and nutrition-sensitive agri-food markets that ensure a fair trade of agri-food commodities.

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CHAPTER

5

The linkage between agricultural input subsidies, productivity, food security, and nutrition

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5.1 Background of the study

Agricultural inputs are a collective term for a range of materials needed to enhance agricultural productivity, and the most important among these are fertilizers and improved seeds. Agricultural inputs are central to agricultural innovation and productivity improvement, but their rising prices make it difficult for smallholder farmers to embrace thereby hindering improvement in agricultural productivity. Agricultural input subsidy (AIS) was, therefore, a key feature of agricultural development policies in rural economies from the 1960s to 1980s (Chirwa and Dorward, 2013) and currently one of the more controversial agricultural policies in sub-Saharan Africa (SSA). AISs are disbursements, monetary concessions, or benefits given by the government to support farmers and are huge spending on public resources (Chirwa and Dorward, 2013; Jayne and Rashid, 2013). AIS is a method for boosting farmers' financial ability to buy inputs they cannot or are reluctant to get at showcase rates. Thus, AIS is considered as a way of attaining higher agricultural productivity, improved food security through lesser food prices and nutrition security (Walls et al., 2018).

Vosters (2018) described subsidies as any disbursement that provides a farmer with an incentive to cultivate a particular crop or follow a precise "best management practice" or retain prices low for customers. AIS is any allowance (or loan, if repaid below market prices) given to lessen the cost of purchasing specific inputs (such as inorganic fertilizer or hybrid seeds) used in agricultural production (Ecker and Qaim, 2011).

Subsidies can be separated into two, depending upon whether they are focused at a specific class of farmers, crops, and land or whether they are applied pretty much consistently (Asfaw et al., 2017). The five AIS programs lately

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executed in Kenya, Malawi, Rwanda, Tanzania, and Zambia are essential examples of the focused/targeted subsidies. These subsidies refer to what is comprehended as another model of pro-poor, focused, and market-friendly "smart" subsidies. These programs practically have some joint and significant characteristics; such as their enormous scope as far as the number of recipients (for instance, 2.5 million in Kenya), time allotment (multiyear—10 years in Zambia), scope (nation-wide), and usage structures (targeted and/or using vouchers). West African countries (such as Burkina Faso, Ghana, Mali, Nigeria, and Senegal) appear to be executing fertilizer subsidies that are widespread (untargeted) in nature, with the targeting of particular crops (instead of farmers). Under this scheme, all farmers who cultivate the focused crops are qualified and receive fertilizer infraction to the size of the area they planted. The application of the universal agricultural input scheme is quite difficult and contains a paper form ("caution technique") requiring the number of bags each farmer is allowed and which is used both at the time of inputs distribution and refund of suppliers/dealers. Both the focused (targeted) and universal subsidies intend to make specific inputs such as fertilizer and seeds available to probable users at prices lower than market costs as a way of incentivizing adoption, increasing productivity and profitability, and finally, poverty as well as encourage economic growth among farming households (Hemming et al., 2018).

Some researchers have identified AIS programs as a popular program among politicians since they provided direct support to rural voters and due to their lack of provision of longer-term investment for infrastructure, they used subsidy as a way of compensating the voters who are mainly the small, poor farmers (Poulton et al., 2010). The theoretical argument for agricultural subsidies is based on their promotion of agricultural productivity by making an investment in new technologies more appealing to smallholder farmers (Chirwa and Dorward, 2013). Usually, the issues raised regarding AISs are about effective targeting, consequences for agricultural budgets, and possible exploitation for personal or political benefit. As a result of these, only SSA farmers use few modern inputs (such as improved seed, fertilizers and other agrochemicals, machinery, and irrigation) (Sheahan and Barrett, 2017).

In developed countries, agricultural, input subsidies have been mostly in the form of price support for both domestic production and export (Maene, 2000), but due to distortion in the global crop prices, the level of domestic supports and export, subsidies were reduced in developed countries under the Uruguay Round Agreement on Agriculture (World Trade Organization WTO, 1995; Bumb et al., 2000). However, SSA has often used AISs to develop agricultural systems, enhance food security by altering relative prices, and encourage farmers to increase the usage of fertilizer and hybrid/modern seeds (Asfaw et al., 2017; Holden and Lunduka, 2014; Jayne and Rashid, 2013). The program also aims to make investments in new technologies more attractive to smallholder farmers. AISs are designed to prevent the extinction of the small farmers and make inputs affordable on a very large scale over a longer period (Druilhe and Barreiro-Hurlé, 2012).

Subsidizing agricultural inputs has been a controversial issue. While the proponents view this as a good government policy, the opponents see it as bad. Opponents of AIS were of the view that that the provision of AIS system is wasteful. Subsidies involve high costs characterized by a lot of fraud and mismanagement (World Bank, 2007b; Ricker-Gilbert et al., 2013). Besides, input subsidy tends to be more beneficial to the wealthier farmers, rather than resource-poor farmers, thereby creating a widening gap between these two classes (Ricker-Gilbert and Jayne, 2012). Late distributions of vouchers causing farmers not to use the inputs such as fertilizers at the right time, thefts of agricultural inputs vouchers, farmers' resistance to using of inputs chosen by the government, and financial inabilities of some farmers to copay the price are also identified (Druilhe and Barreiro-Hurlé, 2012). Jayne and Rashid (2013) observed in their study that the costs of the AIS program often outweigh their benefits. The subsidy in some cases led to tension among villagers, village leaders, agro-dealers, government officers, and lower-level politicians. African AISs are viewed as a wicked problem (Ricker-Gilbert and Jayne, 2012).

This study, therefore, attempts to answer the following questions:

1. What are the merits of AISs?
2. Do AISs have a positive or negative relationship with agricultural productivity?
3. Do AISs have a positive or negative relationship with food security?
4. Do AISs have a positive or negative relationship with nutrition?
5. What are the theoretical and empirical applications of AIS?
6. What are the determinants of supply and demand for AIS? 7. What are the demerits of AIS?
7. What are the demerits of AIS?
8. How can the private sector be involved in AIS?

5.2 The objective of the study

The main aim of the chapter is to assess the relationships between AISs, productivity, food security, and nutrition considering some experiences of some selected countries in SSA. The specific objectives are to:

1. examine the concept of AISs and states the merits,
2. identify the relationship of AIS to agricultural productivity, food security, and nutrition,
3. review the theoretical and empirical applications of AIS,
4. investigate the determinants of supply and demand for AIS,
5. assess the demerits of AIS,
6. identify the roles of the private sector at reducing food insecurity through AIS.

5.3 Justification of the chapter

The understanding of AIS is essential for improving agricultural productivity and growth. Given the widespread use of subsidies for agricultural inputs as a crucial agricultural policy for reducing food insecurity in SSA countries, their specific nutritional effects are not well known, and their role on productivity and food security remains unclear (Assima et al., 2019). The lack of evidence, due to the scarcity of data and impact evaluation studies of AISs on food security and nutrition, lead this study to systematically review the links between the three concepts (input subsidies, agricultural productivity, food, and nutrition security) (Fig. 5.1). The few nutritional outcome studies relating to AIS have often concentrated on the consumption of the target staple, calculated in terms of calorie intake. In light of the impact of food quality on human health and welfare, broader consideration of the impact on nutrition and dietary diversity is important (Walls et al., 2018, Gaiha et al., 2012). Much of the existing literature on inputs such as fertilizer subsidies focused only on program efficiency, crop productivity, and intensity of use. Most of these few available pieces of evidence did not use a systematic approach to show how AISs affect productivity, food, and nutritional status. The evidence base is not large and comes from a few schemes and countries.

Agricultural subsidies in developed countries work through a diversity of methods that offer smallholder farmers, in particular, the incentives to remain in farming, even if not

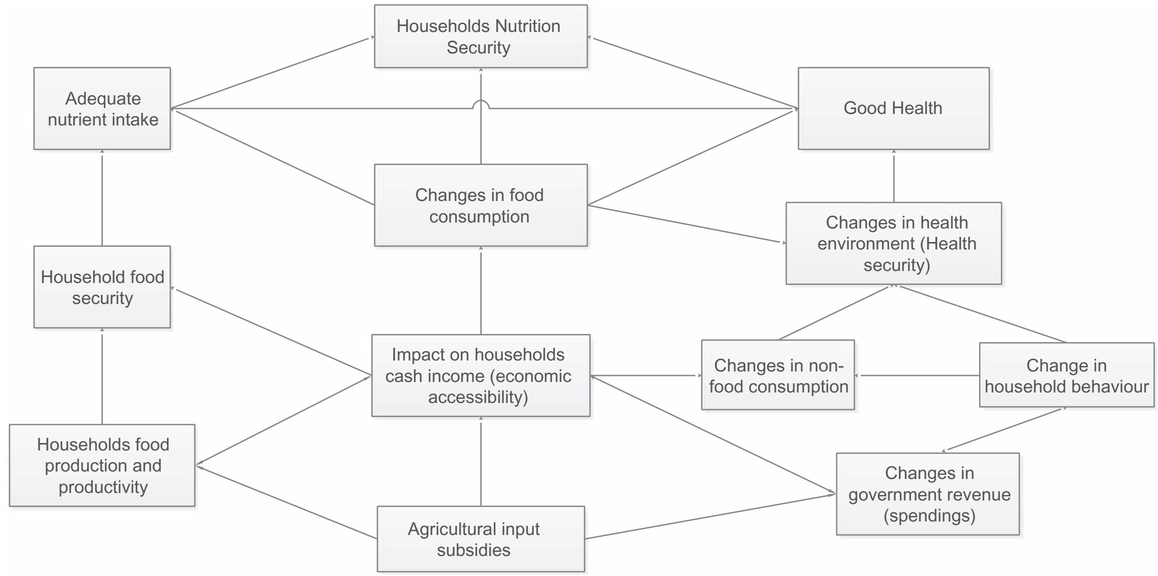

FIGURE 5.1 Conceptual framework of Key pathways from agricultural input subsidies to productivity, food and nutrition securities. *Source: Authors.*

because of output and prices (Josling, 2015). Some countries have recognized methods of regulating policy instruments to look like trade-distorting decreases in support even when incentives are maintained for producers. Emerging and developing countries have expanded their farming help, frequently in manners that mutilate exchange. This chapter raises some questions that need to be faced while further preparing subsidy rules by the World Trade Organization. The resurgence in AISs that started in the early 2000s and expanded during that decade throughout Africa calls for a new wave of rigorous empirical research on the effectiveness of various modalities and challenges for these interventions across countries (Jayne and Rashid, 2013; Minot and Benson, 2009). Understanding the variations in input policy across various countries in SSA and the links between AISs to productivities, food security, and nutrition is useful for the international development and research communities to recognize when evidence is likely to have an impact on policymakers and which stakeholder interests are most important to consider (Resnick et al., 2017).

This chapter seeks to fill this gap to help at strengthening the policy recommendations. Understanding the linkages of AISs to agricultural productivity and how it affects food and nutrition would be of great worth to policymakers and their partners for improving the nutrition sensitivity of agricultural investments. This chapter, in addition, is expected to renew interest in the use of AISs that promote agricultural productivity, food, and nutrition security with a view to give a greater understanding of the advantages and drawbacks of AISs as tools for promoting food and nutrition security and improve productivity.

5.4 Material and methods

This chapter relies extensively on theoretical and empirical literature to address the major questions of the investigation. Information for chapter was obtained principally from secondary sources. Sources include published articles and books, unpublished discussion papers, research reports, national and international databases, policy documents, position papers on AISs, productivity, and food security. The information gathered covers a range of conceptual and empirical issues relating to the advantages and challenges of AISs in SSA, and the importance of the subsidies to agricultural productivity, as well as food security. The study uses a combination of techniques, such as expository analysis and comparative analysis to analyze the information collected.

5.5 Results and discussion

5.5.1 Agricultural input subsidies as a driver of increased productivity and income

The low agricultural productivity is attributable to the low level of agricultural input use such as improved farm inputs, primarily inorganic fertilizers and hybrid seeds (Crawford et al., 2006; Lopez et al., 2017; Mwesigye et al., 2017) for small resource-poor farmers in developing countries. Subsidies are geared toward improving food security in most SSA countries, particularly among vulnerable households. Wealthier, mid to large-scale farmers are able to produce without subsidies and in theory, produce at lower costs to sell cheaply to small-scale farmers. Agricultural productivity requires access and the use of improved seed as one of the critical inputs (World Bank, 2012). AISs are considered a practicable policy to improving agricultural productivity, increasing farmers' income, and achieving national food security (Jayne and Rashid, 2013; Shively and Ricker-Gilbert, 2013; World Bank, 2014; Walls et al., 2018), which are major policy concerns in many postindependence SSA countries. Conceptually, AIS was motivated by the fact that farmers were mostly poor, and they may not be able to allocate limited household income to often costly improved inputs such as improved seeds, pesticides, fertilizer, and agricultural machinery at their market price. This resulted in lower agricultural productivity, and lower incomes, and as such, farmers were locked in a vicious cycle of poverty. Theoretically, as a result of poor road infrastructure and market failures (credit constraints, imperfect competition, and risk of crop failure among others), farmers' private input costs are often higher than true social or economic costs, and as such, input subsidies can generate a positive overall net economic return (Baltzer and Hansen, 2011). In summary, input subsidies encourage farmers' investment in new technologies, which is expected to improve productivity, and consequently, their income (Chirwa and Dorward, 2013).

This section discusses relevant empirical findings on the impact of input subsidies on agricultural productivity and income in Africa. Walls et al. (2018) in their logical review of the impact of AISs on food and nutrition security observed that AISs are a type of social protection frequently considered as a significant method for improving agricultural productivity in low- and middle-income nations. Though, the success and effectiveness of the program still continue contentious with respect to agricultural productivity, food, and nutrition security. Chibwana et al. (2014) utilized a panel dataset to evaluate the Farmer Input Support Program (FISP) in Malawi. The FISP was the first widely acclaimed successful second-generation input subsidy program and had an important knock-on effect in the agricultural policy and political economy landscape of Africa (Jayne et al., 2018). FISP was implemented as a voucher-based input subsidy program, which enabled households to purchase fertilizer, hybrid seed, and/or pesticides at heavily subsidized prices—for instance, 50 kg fertilizer was sold at 8% of the market price. The goal was to promote improved inputs use among smallholder farmers by lowering the market price and was expected to increase productivity. The study reported an increase of 447 kg/ha of maize among farmers who accessed both subsidized maize seed and fertilizer, while an additional 249 kg/ha of maize was observed among farmers who accessed only subsidized fertilizer. Before long, Zambia also implemented the FISP. Using a nationally representative dataset of 3200 smallholder maize farmers, Mason and Smale (2013) investigated the impact of subsidized hybrid seed on maize yield and income in the country. They reported a positive, albeit small impact; on the average, a 10 kg increase in subsidized hybrid seed planted increases household maize output by 106 kg and maize income by 1.1%, among other economic indicators.

Following the food price increases between 2007 and 2008, Africa Rice Centre, as part of the Food and Agricultural Organization's Initiative on Soaring Food Prices implemented an improved rice seed subsidy in 2008. Awotide et al. (2013) evaluated the impact of this program on farmers' output and income in Nigeria. Using an inverse propensity score weighting technique within a randomized control trial approach, the study conclusively showed that farmers in the treatment group (received subsidized improved rice seed vouchers) had higher rice output and income per hectare than the farmers in the control group, even though the latter group cultivated larger rice farms. Specifically, farmers who received subsidized improved rice seed vouchers have a significant increase in their rice income by ₦32,199.03(88.33 USD)[1] per hectare, compared to the counterfactual case that they did not receive any subsidy. Similarly, there was a significant mean difference of ₦25,007.91(68.60 USD) per hectare in rice income between the treatment and control groups.

Similarly, due to the sharp increase in fertilizer prices, the government of Ghana implemented a fertilizer subsidy program, primarily to forestall a corresponding fall in the use of fertilizers by farmers (Baltzer and Hansen, 2011). Wiredu (2015) assessed the effect of this program on the productivity of rice farmers in Northern Ghana. The study reported a modest positive impact; farmers who benefitted from the subsidy had an increase of 29 kg/ha of rice on average, which represents an increase of about 2% relative to nonparticipating households. Furthermore, the Federal Government of Nigeria implemented an electronic voucher-based input subsidy program (Growth Enhancement Support Scheme [GESS]) between 2011 and 2015. The program was aimed at improving fertilizer and improved seeds' use among smallholder farmers, in a bid to boost agricultural productivity and reduce poverty. Accordingly, many studies have evaluated the impact of the program in different regions of Nigeria. For example, Wossen et al. (2017) evaluated the impact of GESS on smallholder farmers' maize yield and income, among other welfare variables. The result showed that maize yield increased by 26.3% among participants relative to nonparticipants, while maize income of GESS participants also increased by ₦19,730 (54.12 USD) per hectare. The study further demonstrated that the impact was not heterogeneously distributed across gender and land size categories. Using Propensity Score Matching approach, the results of Adenegan et al. (2018) also showed that the farm income of the average farmer that participated in GESS in Oyo State (Southwestern Nigeria) improved by ₦119, 927.05 ($399.98), compared to if he/she did not participate in the input subsidy program.

Likewise, Ibrahim et al. (2018) also show that GESS participation positively influenced productivity and farm income among maize farmers in Katsina (Northern Nigeria). Specifically, the study showed that maize productivity for the beneficiaries of the scheme increased by a

[1] 1USD (United States Dollar) is equivalent to ₦362.03.

factor of 2.25, while the productivity of nonbeneficiaries could have increased by a factor of 0.73, if they had benefited from the scheme. Treated farmers' maize income also increased by ₦58,614 (160.79 USD) per hectare, while maize income for nonbeneficiaries could have increased by ₦32,804 (89.99 USD), if they had benefited from the scheme. Some other studies suggest that input subsidies have had a wider impact on the economy through increased food crop production, which resulted in a decline in consumer food prices to the advantage of poor food consumers; and a rise in rural agricultural wages (Druilhe and Barreiro-Hurlé, 2012; Chirwa and Dorward, 2013; Dorward and Chirwa, 2013). Agricultural subsidies increase fertilizer use, average food crop yields, and food crop production, and the success depends on the context, the design, and implementation features (Dorward and Kydd, 2005; Druilhe and Barreiro-Hurlé, 2012; Chirwa and Dorward, 2013). The benefit also varied with the nature of the subsidies and their context in the market.

5.5.2 Agricultural inputs subsidies as a driver of food security

Agriculture has continued to be the lifesaving option for most of the population in terms of its contribution to employment and income generation as well as food security in the developing countries most especially SSA countries (Dillon and Voena, 2018). Agriculture is predominantly occupied by smallholder farmers who engage in small-scale farming (mainly subsistence) and employ traditional methods for cultivating their crops. It is characterized by low productivity, and low economic returns, which are caused by numerous factors such as lack of access to better inputs, inadequate storage facilities, lack of proper processing techniques, inadequate government policies, gender difference in terms of land tenure, sparse transportation networks, adverse effect of climate change such as drought, flood, global warming among others. These have resulted in low economic return and poor agricultural productivity (FAO, 2011; Akaakohol and Aye, 2016).

In the years before the mid-1970s, a number of SSA countries established food security programs by providing farmers with subsidized inputs, agricultural credit, extension services, and marketing facilities, and by regulating markets and food prices (Maxwell, 2001). AIS programs have continued in many SSA countries such as Malawi and Zambia and justified on the basis of the threat of food insecurity from drought and a stagnant economy. AISs improve agricultural production and productivity for small scale resource-poor farmers in developing countries by encouraging the use of improved farm inputs, primarily inorganic fertilizers and hybrid seeds (Mwesigye et al., 2017). This is expected to contribute to increased revenue from sales of produce, improved food security at the household and national level and, hence, contribute to poverty alleviation. There is little insight, however, into the effect of this program on productivity and food security.

A subsidy can only generate a positive net monetary return if there is some market disappointment with the goal that the descending movement in the stockpile bend is more prominent than the absolute expense of the subsidy. Persistent food insecurity and low agricultural productivity in most SSA countries such as Malawi had led to the revival of agricultural subsidies such as fertilizer subsidies in recent years (Harrigan, 2008; Denning et al., 2009). The rising poverty profiles and food insecurity among smallholder farmers in the SSA region are linked to the weak growth of agricultural productivity thereby posing serious concern to the government, policymakers, and other key stakeholders (including donor agencies and academia). One of the significant interventions adopted by the government to combat poverty, improve food security, and enhance agricultural productivity among the farmers in the recent decade is the resurgence of the AIS program (Jayne and Rashid, 2013). In light of the persistent low harvest and high food costs, various SSA nations have initiated AIS programs to improve food production and lessen destitution among small-scale farmers (Frempong, 2018). It is generally believed that subsidizing agricultural inputs will enhance the purchasing power of majorly poor smallholder farmers, thereby increasing their ability to procure more inputs that translate to more output and in doing so increase their level of income that influences the share of both household total food and nonfood expenditure positively and finally have impact on the nutritional outcomes (Walls et al., 2018). As of 2011, about US$ 1.05 billion was spent on AISs by 10 African countries, amounting to 28.6% of their public expenditures on agriculture. Despite the massive spending, access, availability, and use of improved technology (inputs) remain a key constraint to many agricultural smallholders in Africa (World Bank, 2012).

The primary importance of AISs is the ability to result in higher incomes, lowered poverty, and enhanced food security for farmers (Wiggins and Brooks, 2010). However, the efficiency and effectiveness of AISs remain contentious. Thus this section provides empirical findings from previous studies on the role of agricultural subsidies as a driver of food security. It is worthy to note that there is a massive gap that exists in the literature as far as the impact of AISs on smallholder farmer food security is concerned. Jayne et al. (2018) identified only two studies (Gilligan et al., 2009; Karamba and Winters, 2015) that have assessed the impact of AIS on food security. Similarly, Walls et al. (2018) also noted the lack of ample studies on the subject matter, thus causing limitation in accessing studies for review.

Kato and Greeley (2016) reported that Malawi has generally been successful in increasing agricultural input use leading to an increase in maize production, maize yields, and food security under favorable economic and weather conditions as well as the promotion of private rural input business in Malawi. Similarly, Chirwa and Dorward (2013) observed that input subsidy in Ruvuma Region of Malawi had led to a fall in maize prices, an increase in local agricultural wages, and promoted net food buyers and labor-surplus smallholders.

In Tanzania, Lameck (2016) observed that food insecurity was associated with a low rate of application of fertilizers and usage of improved seeds among smallholder farmers due to high fertilizer and seed costs, which led to an increase in food prices. Lameck (2016) studied the impact of agricultural subsidies on smallholder maize farmers with a specific focus on agricultural productivity, food security, usage of improved inputs, and farmers' perception of how the program functioned. The investigation involved 60 smallholder farmers who received subsidies and 60 who did not. The study findings show that most farmers agree that the availability of maize stored in their household makes them feel secured in terms of food. In addition to that, 90% of the farmers who received subsidies have a positive opinion on the improvement of food security due to their participation in the subsidy program. However, it was observed that the study does not establish causality and thereby made it challenging to rely on the effect.

Mkwara and Marsh (2011) in their assessment of the impact of smallholder fertilizer subsidies on national and household food security in Malawi observed that at the national level, food security has direct effect on fertilizer subsidies, but at the household level, maize production was severely lopsided, with the south lagging behind the center and the north. In the short-to-medium term, the authors suggest substituting the use of a universal subsidy program in Malawi with a more targeted one.

Gilligan et al. (2009) assessed the favorable impact of Ethiopia's Productive Safety Nets Program (PSNP) and its linkages. This social protection program is the largest of its kind in SSA outside South Africa. The program had four goals primarily: to provide transfers to the food insecure population; to prevent the sales of household assets; to create assets at the community level; and to bridge the food gap that arises when there are insufficient income and food production. The study used the Propensity Score matching to assess the impact of the PSNP and other food security programs after their first 18 months of operation on household food insecurity and concluded that there was an improvement in one measure of the household food security (caloric acquisition above a minimum threshold).

The small demand for agricultural input in SSA countries has been acknowledged to be brought about by insignificant use, auxiliary market contacts, for example, high transportation costs, value variances, or a frail conveyance framework keeping farmers from approaching quality sources of inputs or to help present-day agriculture monetarily (Liverpool and Winter-Nelson, 2010; Conley and Udry, 2010, Dercon and Gollin, 2014; Collier and Dercon, 2014). Increasing expenses of farm inputs debilitate their utilization and lead to a decrease in commodity supply and the painfulness of farmers. The greater part of the farming sources of input has been dependent upon sensational cost increments (FAO, 2009). Once in a while, farmers are subsequently ready to bear the cost of bought inputs especially those that are not part of the government-supported plan since they have restricted buying power as their normal yearly income per household. Low and capricious rainfall is firmly connected to low utilization of purchased inputs as it makes extra yield hazard, and farmers are hesitant to apply inputs in light of the precariousness of yield costs, for dread that they may not take care of expenses (Gordon, 2000).

Liverpool-Tasie (2012) discovered that farmers' investment in the subsidy program does not influence their interest in commercial fertilizer; however, the choice to take an interest in the program positively affects the amount of commercial fertilizer bought. One main reason for executing input, for example, input subsidy is the need to battle the disturbing decrease in soil nutrients in many different parts of Africa and the requirement for their renewal. Subsidies to advance fertilizer application may then be advocated as far as positive externalities where expanded fertilizer use prompts higher farm yields, decreases in soil disintegration and downstream flooding and siltation, in deforestation and carbon discharges, and decreases in poverty and provincial urban movement.

5.5.3 Linking agricultural input subsidies to nutrition

Nutrition security exists when, other than access to a healthy and balanced eating routine, individuals likewise have access to sufficient caregiving practices, and to a protected and clean environment that permits them to remain sound and utilize the foods they eat (Ruel, 2013). Three explicit variables that impact nutrition status are food, well-being (health), and treatment, which directly affect the consumption of nutrients and the occurrence of disease (Ruel, 2013). The amount, assortment, and nutritional quality and safety of foods in diets are to a great extent influenced by the accessibility and availability of different foods whether available from the market or from farmers' own production. There is no universal pathway through which AISs affect nutrition outcomes. However, the results of all the literature reviewed in this study show a kind of indirect links between AISs and nutrition. Johnson-Welch et al. (2005) suggest that the promotion of smallholder agricultural production through AIS will lead to more food products entering the market, leading to lower food prices, greater access to food and micronutrients by the poor people. Agricultural input policies such as fertilizer subsidies may increase staple food production, thereby improving food availability and increased energy intake. It can also encourage diversity of food production, including vegetables, fruits, and animal source foods through improved productivity. In this case, it directly affects smallholder nutrition and diet quality (World Bank, 2007a). AISs help to increase the purchasing power of large numbers of small farmers by lowering commodity prices, which should lead to increased demand for nonstaples food and off-farm products and services, boosting nearby labor requests and compensation and improve individuals' nutrition (Chirwa and Dorward, 2013). The diminished expenses of subsidized inputs increase their profitability and reduce the apparent dangers by farmers with inadequate information on input benefits and appropriate utilization. Absence of agricultural input such as subsidies on seeds can make it hard to improve yields and efficiency in the production of nutritious foods. Agricultural productivity can be improved by giving prompt access to inputs, expansion of rural and marketing infrastructure, and adherence to timelines in subsidized inputs delivery to the farm households (Gulati et al., 2012, Webb and Block, 2012; Shively et al., 2012).

Shankar et al. (2019) in their study of a "systematic review of links between agricultural inputs and diet and nutrition outcomes of farm households in South Asia," observed that studies have gradually and consistently been developed since the mid-2010s on the effect of agricultural inputs on diet and nutrition outcomes of farm households, yet there is still a far way to go. Shankar et al. (2019) results suggest that while there is no sign that land possession or size alone has a clear relationship with farm household dietary or nutrition outcomes, land productivity due to AIS is more clearly connected with improved nutrition. However, studies, for example, connecting specific inputs such as improved seeds or irrigation with nutrition remain very few.

5.5.4 Case studies of countries using agricultural input subsidies to boost food security in sub-Saharan Africa

In SSA, Asfaw et al. (2017) discern three specific types of program design for farm input subsidies. Demonstration packages were used in the mid-1990s, and large-scale multiyear projects were later introduced that was targeted in East and Southern Africa, and universal in West Africa. In the early 2000s, AISs were introduced in many countries as demonstration packs with the main objective of bringing issues to light about the utilization of fertilizers and showing their usefulness to smallholder farmers. Demonstration packs such as the Starter Pack (universal, rationed subsidy) and Targeted Input Programme (targeted version of the Starter Pack) implemented in Malawi, or the Sasakawa Global Initiative programs implemented in several African countries in the mid-1990s to early 2000s (Druilhe and Barreiro-Hurlé, 2012) were the programs introduced on a consistent basis (one to a few years) to give modest quantities of free or intensely subsidized fertilizer to countless farmers, usually as a component of a complementary input and training/extension package. The second approach of the use of AIS encompasses subsidizing inputs so as to make them more inexpensive on a large scale and over a longer time period, with the aim of expanding national production and productivity.

This section gives brief synthesizes findings from SSA countries case studies of AISs even though several SSA countries, including Mali, Zimbabwe, Zambia, Mozambique, Malawi, Tanzania have AISs policy to boost agricultural production in order to improve food security. Countries such as Zambia, the United Republic of Tanzania, Kenya, Nigeria, and Ghana run a targeted input subsidy program (e.g., fertilizer voucher program) under which farmers who satisfy various essentials, for example, growing targeted crops (usually staple crops), having smallholdings, as well as being situated in specific area, are qualified and get a volume of subsidized inputs. These vouchers permit moving buying capacity to smallholder farmers either by diminishing the price of the input at a price beneath market (for example United Republic of Tanzania) or by permitting farmers to get a foreordained volume of fertilizer at a fixed discounted cost as in the case in Malawi (Riesgo et al., 2016). Countries such as Ethiopia where the universal subsidy program is in use, the government imports agricultural inputs (such as fertilizer) and distributes it among farmers at below market price via cooperative unions network.

The Zambia Fertilizer Input Support Programme in 2002 was introduced to allocate inorganic fertilizers to farmer groups and later rechristened when other inputs such as hybrid maize seed were included in the dissemination. Fertilizer Input Support Programme is an input subsidy aimed at improving the asset base of small farmers and advancing farming as a business for smallholder farmers, just as supporting on-farm production and nearby accessibility of maize to escape food insecurity. Evaluations of this input programme, however, have discovered that more unfortunate (poor) farming households cannot access the program, which therefore tends to benefit mainly wealthier farmers; with a general improvement in yields. According to the findings by Chapoto et al. (2015) is found not to have fulfilled its objectives of food security, reduction in hunger, or improvement in households' assets.

The most widely discussed Malawi Farm Input Subsidy Program (FISP) smart subsidies in Africa was introduced in the 2005/2006 season as a result of weather shocks that affected production and caused persistent food shortages. Malawi FISP was initiated to improve poverty and guarantee the nation's food security by upgrading agricultural productivity and yields (Arndt et al., 2016). Vouchers are given, permitting qualified farmers to trade them for fixed measures of inputs at subsidized rates, with the essential point of raising the food self-sufficiency of asset poor smallholder farmers and income through expanded maize yield (Asfaw et al., 2017, Lunduka et al., 2013). Findings from previous studies such as Chibwana et al. (2012) showed that Malawi's FISP had led to a stagy upsurge in maize productivity since the execution of the program. National maize yields were reported to have increased from 1.06 million tons to 3.62 million metric tons over the duration of the program. Also, the empirical finding by Schiesari et al. (2016) also revealed that the Malawi FISP increased productivity, households' income, and rural wages as expected from theory, but failed to improve access to food at the national level. This study acknowledged a high cost and targeting inefficiency as limitations for preserving the input subsidy program.

As a case study, the United Republic of Tanzania presents itself as a long-standing champion of AISs. It has subsidized the costs of seed and fertilizer to farmers for many years, and as a result, the country has remained largely food secure. In Zimbabwe, subsidies are apparently paid for nonfood, largely export-oriented crops such as tobacco and cotton. Credit support is a major source of agricultural assistance, largely as a response from the donor community to food shortages at the household level. Contrast with African nations, for example, Malawi or Tanzania where AISs programs have been focusing on a huge number of farmers and expending a lot of the national agriculture spending plan, Mozambique's fertilizer input subsidy program is a small scheme, in terms of total number of recipient (farmers) covering only 0.5% of the farmers owing to deficiency of economic resources (FAO, 2016).

Nigerian government as a component of her AISs started the GESS to improve agricultural production by offering "smart subsidies" on certain farm inputs to small-scale farmers (Amurtiya et al., 2018). The discoveries from the investigation uncovered that the scheme had the option to convey subsidized agricultural inputs to small-scale farmers moderately, effectively, and at a reasonable rate, which assisted with expanding farm yield. Be that as it may, the plan is influenced significantly by its politicization, the failure of the governments to discharge funds to agro-vendors prompting late conveyance of inputs and the absence of support service (extension) to farmers

In Ghana, the relic of subsidizing inputs dates back to the 1970s, when the government monopolizes the early version of the program for importation and distribution, as in many other countries. With the acknowledgment that the early program was financially unreliable and damaging to Ghana's macroeconomy, in the early 1980s and compulsion from the World Bank and other donors, the parastatal-led subsidies were phased out in the late 1980s and detached by 1990 (Jebuni and Seini, 1992; Resnick and Mather, 2015). The entire supply chain of fertilizers was then managed by the private sector (Resnick and Mather, 2015). Fertilizer subsidies were reinstated in 2003 in Ghana for the country's main cash crop (cocoa) and in 2008 for food crops (such as maize) and named Ghana Fertilizer Subsidy Program (GFSP). Under the GFSP, more food crops such as maize, rice, and soybean seed inputs were introduced in 2012 (Resnick and Mather, 2015). The GFSP was intended to be an impermanent program; however, it has gotten a normal (and obviously perpetual) some portion of the agricultural budget of Ghana. The revived subsidy program came to fruition for various reasons, including inspiration from the private sector, fertilizer and food price rises, political ubiquity and unavoidable decisions in 2008, and the observation that Ghana confronted testing issues of soil barrenness and undernormal fertilizer use among African countries (Banful, 2011; Resnick and Mather, 2015). On the link between AIS and food security, Wiredu (2015) discovered a direct effect of subsidized fertilizer on food security of smallholders of rice in northern Ghana and proposed extra strategy measures to improve food security.

The case of Kenya: Kenya subsidizes the production of food crops in order to achieve sustained levels of availability. Subsidizing output means the government, on behalf of farmers, procures agricultural inputs and distributes these inputs to farmers below the rates of the commercial outlets. The goal is to reduce farming costs, thus keeping the prices of output relatively inexpensive and accessible to consumers. Examples of inputs that are subsidized are fertilizers, hybrid maize, and sorghum seeds and land ploughing/tractor services.

5.5.5 Drawbacks in agricultural input subsidy

Agricultural subsidy programs are intended to promote the growth of input supply systems by taking careful account of the structure, conduct, and performance of input supply markets, careful program design, efficiency-focused, and long-term trust between governments and private suppliers. However, unclear program design and various problems in implementation (Obayelu, 2016) coupled with quick exits and unstable/changeable subsidy programs have hindered the program from yielding the expected effects (Chirwa and Dorward, 2013). These challenges along with others have been the major concern by a lot of subsidy analysts (such as Crawford et al., 2006; Morris et al., 2007; Jayne et al., 2009; Bumb et al., 2011) over the years. Campbell systematic review in 2018 on the "effects of input subsidies on agricultural productivity, beneficiary incomes and welfare, consumer welfare and broader economic growth" revealed that subsidy schemes though results in positive results for purchasers and more extensive monetary development, in any case, proof have demonstrated that they are inclined to wastefulness, inclination, and defilement in the SSA (Hemming et al., 2018). The reintroduction of input subsidies in some countries (such as Kenya, Malawi, Rwanda, the United Republic of Tanzania, Zambia, Mozambique, Nigeria, and Ghana) frequently caused extensive strain among the government and contributors. The position of the contributors fluctuated over time and was not reliable even inside similar organizations (Potter, 2005; Chirwa and Dorward, 2013), due to either contrasts in a belief system or absence of proof on the impacts and adequacy of the subsidies. In general, the main challenge of AISs alludes to a history of inefficiencies due to mismanagement and scam.

The program's execution has likewise been imperfect because of the regular late conveyance of vouchers, debasement, benefactor customer relationship, politicized voucher distribution, unlawful arrangement among leaders and agro-vendors, missing vouchers, and resale of vouchers by farmers. The investigation saw that subsidy vouchers do not generally arrive at farmers in the amounts proposed. Nonetheless, even those that arrive at the farmers are not constantly utilized, and consequently, the supply of subsidized inputs may not really increase in outright terms the number of inputs utilized by farmers. Various studies (Ellis et al., 2009; FAO, 2015) have stated first-class catch and illegal conduct as a significant issue with AISs. Quantitative and qualitative studies have also shown that unclear input subsidies program design in some countries besides the problems in implementation has made it unlikely challenging to yield the expected effects. African AISs are targeted based on political considerations rather than, beneficiaries' inability to afford the inputs at unsubsidized prices or the expected profitability of the subsidized inputs, thereby undermining the stated objectives (Pan and Christiaensen, 2012). Operational challenges affecting AIS involve identifying the required inputs for distribution in collaboration with service providers and planning for the seasons. Limitations in logistics and human resources often hinder the timely delivery of inputs (Cantore, 2011). For instance, in 2009 the distribution of vouchers in Rwanda was discontinued due to difficulties in printing and on-time issuance to farmers (Mwesigye et al., 2017).

5.5.6 Roles of the private sector in agricultural inputs subsidy

Smart AISs are distinguished from universal input subsidies of the 1980s by three design principles: its emphasis on targeting specific farmers who do not already utilize the agricultural input being subsidized (usually the poorest and most vulnerable households); its reliance on private sector supply networks to distribute as opposed to government distribution systems; and the existence of a firm and credible exit strategy (Baltzer and Hansen, 2011). AIS programs had been established to encourage increased participation of the private sector in the transfer of technology to farmers (Mwesigye et al., 2017). Private companies have been involved in a myriad of ways. Shreds of evidence have shown that the private input suppliers are largely replacing the parastatals of the green revolution era and now provide an increasing volume of diverse products such as improved seed and breeding stock, fertilizers, agrochemicals, feed, and mechanization. The private sectors helped at reducing food insecurity, especially in developing countries, through the provision of agricultural inputs in a proficient, practical, and manageable way. Private sector interest in the subsidies on some occasions is disturbed by inconsistent changes in the projects. All together for input supply organizations to assume this significant job, there is a need to build and keep up suitable infrastructure and institutions for innovation spread by the government as well as being consistent and straightforward in government choices. The integration of the private sector in the execution of a large and nation-wide AIS program according to Imperial College (2007) makes the program to be done more efficiently with less bureaucracy associated with state delivery of services. Second, private sector engagement in agricultural input makes it feasible for the government to utilize rare assets on different tasks through a decrease in expenses in subsidy. Third, private sector participation is seen as a strategy for improving the private market system. Fourth, private sector inclusion in input retailing diminishes the removal of fare deals by financed inputs. Chirwa and Dorward (2013), in their results of findings on private sector involvement in input subsidy program in Malawi, discovered that increasing the investment of the private sector in the subsidy program not just empowers the development of the private sector in input but likewise improves the productivity of the program's execution.

The GESS launched by the Federal Government of Nigeria in 2012 highlights the importance of the private sector inclusion in the implementation of AISs. The previous system of fertilizer subsidy was characterized by the complete dominance of government in fertilizer delivery, from procurement to retail. In order to do this, the government had to maintain staff and offices/warehouses in all 36 states, 776 local government areas as well as outlets at the ward levels (a ward is the smallest unit in the political architecture of Nigeria). This bureaucratic system was rife with inefficiencies (late distribution of fertilizers) and wide-scale corruption (large scale diversion and smuggling of subsidized fertilizers), so much so, that it is estimated that farmers actually got only 11% of the subsidized fertilizers. Indeed, interested farmers often had to buy subsidized fertilizer at unsubsidized prices (Grossman and Tarzai, 2014; Grow Africa, 2016).

Thus the primary policy objective of GESS was to divest the government from the implementation of the subsidy program, by leveraging on the private sector for input distribution. Thus, the government disengages itself from the direct supply of fertilizer to performing facilitation functions such as regulation of fertilizer quality and provision of enabling environment to make fertilizer value chain a private-sector-driven (Grossman and Tarzai, 2014; Uduji et al., 2019). This was done by registering existing agro-dealers and facilitating a conducive business environment by supporting the sector with a government-backed credit guarantee program, which worked to mitigate the risks of lending by commercial banks to agriculture.

The GESS approach has been more successful on two fronts: a wider reach of the fertilizer subsidy and a reduction in government subsidy expenditure. Compared to the diversion of an estimated 89% of the subsidized fertilizers under the old system in which the government was in charge of the whole process, GESS delivered subsidized inputs to one million farmers in 2012 and grew to five million farmers in 2013. Second, while the government expended about US$180 million to subsidize fertilizer, most of which never reached the intended beneficiaries in 2011 (the year preceding GESS), 1.2 million farmers were able to purchase subsidized fertilizers under GESS in 2012 at a cost of about US$53 million to the government. This implied that the cost per farmer had reduced from about US$230 to US$46 in just under a year. By the second year of GESS implementation, 4.3 million farmers benefitted from the fertilizer subsidy program at a total cost of about US$96 million. Thus engaging the private sector had freed up scarce government resources that had other important alternative uses, increased the efficiency of the subsidy program in terms of reach, and created additional jobs along the private sector fertilizer value chain (Grossman and Tarzai, 2014; Grow Africa, 2016).

5.6 Conclusion and Recommendations

The chapter aims to establish what is known through literature about AIS and the relationships with agricultural productivities, food, and nutrition security. Some policy implications have been generated from this review. This study observed that AIS is an efficient way to support a country by increasing productivity to produce enough food for household consumption and surplus for the market. There is almost a complete lack of studies that systematically review the links between AISs and productivity and explaining the implications of food security and nutrition. We investigated whether literature established links between AISs, agricultural productivity, food, and nutrition security. The outcomes from the review and the experiences of selected countries show that there is a link between AISs, agricultural productivities, food, and nutrition security. While input subsidies have a kind of direct link with productivity, the relationship to foods and nutrition security appears to be indirect. In order for AISs to have any meaningful effect, subsidies need to be "smart," with a clearly defined purpose, and instruments are intended for that purpose.

This chapter also confirmed that though AIS is a contentious issue in policy debate, the policy leads to agricultural productivity, and agricultural productivity, in turn, enhances food and nutrition security although with some drawbacks in an attempt to implement the subsidies program. Subsidized input systems looked good to farmers, but the theoretical problems in terms of diversion and inefficiency have limited the actual benefits to farmers. Investment in AIS programs has the potential to raise agricultural productivity, with development benefits including food and nutrition security. The work has the merit of being able to set a baseline for future studies on nexus of AISs, agricultural productivities, food, and nutrition security.

To overcome some of the drawbacks in AIS, there is a need for clarity in subsidy program objectives as well as appropriate design and implementation plans to achieve such objectives. The private sector involvement for procurement and delivery, monitoring and evaluation of programs should be strengthened. Input subsidies should be aimed more directly at disadvantaged, small-scale farmers, to serve as social protection. Subsidies should not be continued after farmers have learned about the use and benefits of inputs to discourage farmers' overuse of inputs, incurring deadweight, and administration costs and also potential environmental costs. Also, to increase agricultural productivity and ensure food security, subsidies should not be applied to inputs and technologies that are not fundamentally profitable.

5.7 Additional Research

Based on the findings in this chapter, we suggest that future research could be directed at: (1) evaluating the impact of transitions in AISs on prices of agricultural produce, food, and nutrition security; (2) conducting an economic analysis of input subsidies on agricultural productivities, food, and nutrition security among smallholder farmers; (3) identification of alternative ways of reducing the costs of the AISs while still increasing agricultural productivity, food, and nutrition security of smallholder farmers, given the huge budgetary implications of the subsidies. Our study could not accomplish these due to limitations of data, time, and funding.

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CHAPTER

6

Diversifying crops for food and nutrition security: A case of vegetable amaranth, an ancient climate-smart crop

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6.1 Introduction

Drought is a major abiotic stress that causes severe crop losses worldwide reducing crop yield significantly (Fahad et al., 2017; Kogan et al., 2019). It affects household food security for more than 1.1 billion people in South Asia and sub-Saharan Africa who are largely dependent on the agricultural sector for their livelihood (Vermeulen et al., 2012; Ali et al., 2017; Twongyirwe et al., 2019). Given the climate change and population growth predictions, current agricultural practices will not be able to support the nutritional requirements of a projected nine billion people by 2050 (UN DESA, 2011). Despite phenomenal improvement on the production of major staple crops as a strategy for enhancing food security, the production of maize (*Zea mays*), rice (*Oryza* spp.), and wheat (*Triticum aestivum*) are now decreasing, already affected by drought (Elliott et al., 2014; Kadam et al., 2014; Daryanto et al., 2016). Overreliance on these genetically homogenous carbohydrate-rich staple crops means that malnutrition and micronutrient deficiencies remain major global concerns (FAO, 2017). Increasing leafy vegetable consumption is one of the strategic interventions to eradicate disease associated with micronutrient deficiency, but the consumption levels and frequency are still low to guarantee such benefits (Birol et al., 2015).

Diversifying the global food basket with a wide range of underutilized (see Mayes et al., 2011 for definition) leafy vegetable crops with increased drought tolerance and adequate dietary micronutrients is one way to enhance

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global food security (Chivenge et al., 2015; Massawe et al., 2016; Mustafa et al., 2019). Underutilized or neglected crops such as amaranth (*Amaranthus* spp.), Chinese kale (*Brassica oleracea* var. alboglabra), and winged bean (*Psophocarpus tetragonolobus*) contain desirable features such as high nutritional properties, disease resistance, and abiotic stress tolerance (Mabhaudhi et al., 2016). These crops were once cultivated by local farmers with low input needs (Mabhaudhi et al., 2016), but have become neglected due to low agronomic value and lack of socioeconomic awareness (Padulosi et al., 2013). In addition, remarkable promotion toward formal seed systems and markets on the major crops to support farmers made underutilized crops less competitive and attractive (Chivenge et al., 2015).

Crop diversification may suppress pest outbreaks and reduces pathogen transmission (Lin, 2011), lessens the risks of monoculture, and improves soil conditions which may worsen under future climate conditions (Njeru, 2013; Saraswati et al., 2013; Mustafa et al., 2019). Underutilized crops have the potential to be better adapt to the adverse effects of climate change due to their wide genetic diversity and adaptive capacity harbored within landraces (Massawe et al., 2005; Brenner et al., 2010). With good adaptation to marginal lands and high nutritional content, they can constitute an important part of a human's diet, to complement with the staple crops (Jain and Gupta, 2013). With a good prospective marketing strategy, they have the potential to achieve high values in markets globally (Ebert, 2014). However, due to consumer preference for familiar and common food products, introducing unfamiliar vegetable crops is still challenging (Jaenicke, 2013). In addition, underutilized crops are often neglected by mainstream research due to the fact that they are not commercially important (Jaenicke, 2013), and thus knowledge related to genetics and physiological traits of underutilized crops is limited (Sogbohossou et al., 2018).

Recently, due to the increased recognition of the value of agrobiodiversity, sustainability, and improved human health, underutilized crops have become popular due to their excellent features as climate-resilient crops with high nutritional properties (Mayes et al., 2011; Padulosi et al., 2013; Khoury et al., 2014; Massawe et al., 2016; Cheng et al., 2017). Therefore it is important to identify significant traits in underutilized crops that currently exceed the equivalent trait in major crops, such as drought tolerance, and the need to have a good perspective in markets, which will be worth investment from the very limited resources available (Mayes et al., 2011). In addition, promoting strategies in transferring knowledge to consumers, including younger decision-makers and well-coordinated market supply chains could increase the consumption of underutilized vegetables (Gido et al., 2017b).

Among underutilized crops, amaranth is considered a promising crop for cultivation in marginal, arid, and semiarid regions because of its nutritional benefits, substantial genetic diversity, and its ability to withstand drought (Allemann et al., 1996; Sarker and Oba, 2018; Dawson et al., 2019; Jamalluddin et al., 2018). Amaranth is one of the three important pseudocereals, along with buckwheat (*Fagopyrum esculentum*) and quinoa (*Chenopodium quinoa*) (Pastor and Ačanski, 2018), and it is an indigenous vegetable commonly consumed in Asian, African, and South and Central American households. It is among the cheapest leafy vegetables available (Varalakshmi, 2004), with leaves that taste similar to spinach (Rastogi and Shukla, 2013).

Amaranth (*Amaranthus* spp.) belongs to the Amaranthaceae family within the order Caryophyllales, which contains nearly 180 genera and 2500 species (Sauer, 1993). *Amaranthus* along with *Chenopodium* (quinoa and canahua), *Beta* (beet and sugar beet), and *Spinacia* (spinach) are the cultivated genera in the family. *Amaranthus* genus consists of approximately 60–70 species grouped into three subgenera (Mosyakin and Robertson, 2003): *Amaranthus Acnida*, *Amaranthus Albersia*, *Amaranthus Amaranthus*. Subgenera *A. Amaranthus* comprises of three cultivated grain species (*Amaranthus caudatus*, *Amaranthus cruentus*, and *Amaranthus hypochondriacus*), while subgenera *Amaranthus Albersia* consists of 17 vegetable species (including *Amaranthus tricolor*, *Amaranthus blitoides*, *Amaranthus blitum*, *Amaranthus viridis*, and *Amaranthus graecizans*), and subgenera *A. Acnida* consists of weeds (*Amaranthus spinosus* and *Amaranthus palmeri*) (Das, 2012; Achigan-Dako et al., 2014).

Amaranth uses the C_4 carbon cycle, which is more common in grasses but rare in dicots (Stetter et al., 2016). Partly as the consequence of its C_4 photosynthesis, amaranth has high water-use efficiency and the ability to maintain CO_2 fixation during drought stress conditions (Omami and Hammes, 2006). Amaranth has the capacity to change its phenotype and physiological characteristics in response to environmental changes, such as exhibiting an indeterminate flowering habit, growing long taproots, and extensive lateral root systems in response to drought stress (Kadereit et al., 2003). The presence of high genetic and phenotypic diversity in vegetable amaranth provides an excellent opportunity for breeding and varietal development with increased drought tolerance characteristics (Alemayehu et al., 2014; Sarker and Oba, 2018; Sarker et al., 2018) (Fig. 6.1).

This chapter presents information on the potential of leafy vegetable amaranth as a climate-resilient and nutrient-dense crop for food and nutritional security in a changing world. It looks at the crop's past and present research endeavors and the prospects for future research to support sustainable crop production with the purpose of combating malnutrition and micronutrient deficiency and to enhance global food security.

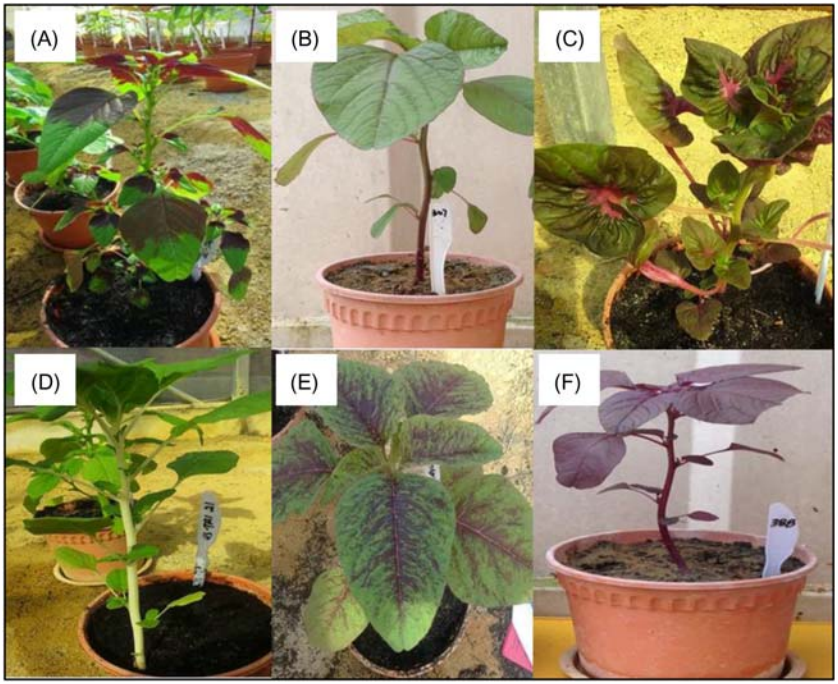

FIGURE 6.1 The variability of characters among selected *A. tricolor* accessions: (A) basal area pigmented leaf, (B) vein pigmented leaf with red stem, (C) pink spotted leaf with pink petiole and stem, (D) green leaf with white petiole and stem, (E) green leaf with spotted purple, and (F) perfect red amaranth.

6.2 Amaranth in a nutshell

Amaranth is among the oldest crops found in the Americas, with archeological evidence suggesting that grain amaranths were cultivated in Mexico as early as 5000 BCE (Sauer, 1950). The grain is native to Mexico and Guatemala and consumed as a sweet snack named "alegria," where the grains are toasted and mixed with honey and chocolate or milled into flour (Sauer, 1967). The rich color of the flower and leaves were used as dyes in religious rites and cultural roles in pre-Columbian civilizations (Sauer, 1967, 1950). Later, due to its involvement in a sacred indigenous religious routine, the cultivation of grain amaranth was actively suppressed during the Spanish conquest (Sauer, 1976, 1993; Iturbide and Gispert, 1994). By the 18th century, amaranth was introduced into Europe and was widely distributed to Africa and various parts of Asia as grain (pseudocereal) and vegetable crops (Sauer, 1993). Currently, it has worldwide cultivation, mostly in warm temperate and tropical regions (Parra-Cota et al., 2014). The leafy vegetable type of amaranth, specifically *A. tricolor*, was most likely originated in India and was later introduced to South America (Martin and Telek, 1979), and has been extensively cultivated in Southern China (Rastogi and Shukla, 2013).

Amaranth has experienced whole-genome duplication events in its evolutionary history with most species having a haploid chromosome number of $n = 16$ (*A. hypochondriacus*, *A. caudatus*, *Amaranthus quitensis*, *Amaranthus edulis*, *Amaranthus powellii*, and *Amaranthus retrolexus* L.) or $n = 17$ (*A. cruentus*, *A. tricolor* L. and *A. spinosus* L.) with exceptions of *Amaranthus dubius* with $n = 32$ (Grant, 1959; Lightfoot et al., 2017). The evolutionary origins of vegetable amaranths have not been conclusively determined; however, extensive studies using molecular markers have shown that all three monophyletic grain amaranth arose directly from polyphyletic weedy amaranth *Amaranthus hybridus* in multiple independent domestication events (Mallory et al., 2008). Clouse et al. (2016) also confirmed that *A. hybridus* could be the progenitor species of the grain amaranth based on single nucleotide polymorphism (SNP) neighbor-joining analysis, supporting results showing a close relationship between *A. caudatus* and *A. hypochondriacus* (Kietlinski et al., 2014; Stetter and Schmid, 2017). While the marker studies have improved phylogenetic understanding and genomic resources in grain amaranth, its evolutionary relationship with leafy vegetable amaranth is still unclear, and limited information is available on the use of molecular approaches in leafy vegetables (Khaing et al., 2013; Stetter and Schmid, 2017).

Floral parts and seed morphology are the most suitable way of distinguishing grain and vegetable amaranth (Trucco and Tranel, 2011). Grain amaranth consists of larger apical inflorescences compared to vegetable amaranth, comprising aggregates of cymes, five tepal lobes, and five stamens. The seed coats are well-defined flange, utricle circumscissile with various colors (Das, 2012). On the other hand, vegetable amaranth can be distinguished by its inflorescence and indeterminate growth habit, possession of axillary glomerules or short spikes, flower buds from the leaf axil, three tepal lobes, and stamens, and it has brownish—black seed with undifferentiated folded flange. Despite the well-defined characters to distinguish grain and vegetable amaranth, species differentiation based on morphology features have always been challenging, due to substantial dissimilarities found between and within species (Mandal and Dhangrah, 2009), along with broad geographical distribution (Mujica and Jacobsen, 2003) and environmental influences on the phenotype and physiological characteristics (Sauer, 1967; Espitia, 1992).

It is possible but challenging to produce hybrid amaranth. The cultivated varieties of amaranth are monecious (Mosyakin and Robertson, 2003) and primarily self-pollinated (Das, 2016), with female and male flowers arranged in close proximity (Murray, 1940). Some weedy amaranth including *Amaranthus tuberculatus* and *A. palmeri* are diecious (Trucco and Tranel, 2011). Amaranth may combine their natural ability of self- and cross-pollination through the wind, with average outcrossing of 4%−34% (Pal and Khoshoo, 1973; Kulakow and Hauptli, 1994; Brenner and Widrlechner, 1998). While some of the amaranth species are dioecious, where outcrossing is a must, the variation in outcrossing is dependent on the ratio of staminate to pistillate flowers, and pollinators such as insects could also account for some variability in outcrossing rates (Hauptli and Jain, 1985). Amaranth species can be cross incompatible. For example, failed outcrosses between grain *A. cruentus* with *A. hypochondriacus* and *A. caudatus* due to pollen sterility have been reported, that is pollen did not complete fertilization on the cross parent stigma (Greizerstein and Poggio, 1994). However, hand emasculation technique has been used to successfully produce inter- and intraspecific grain amaranth F1 offspring (Stetter et al., 2016).

Amaranth requires less water for cultivation compared to maize, wheat, and cotton (*Gossypium hirsutum*) (Kauffman and Weber, 1990), although too little water can cause early flowering (Schippers, 2004). It can grow in saline (Huerta-Ocampo et al., 2014; Saucedo et al., 2017; Sarker et al., 2018) or poor fertility soils (Nasir et al., 2016) with a low nitrogen requirement (Ejieji and Adeniran, 2010). Soil rich in nitrogen is beneficial to vegetable amaranth as high levels of nitrogen will delay the onset of flowering, thus providing higher leaf yield (Schippers, 2004). Amaranth grows well in high temperature 30°C/25°C day/night (Khandaker et al., 2009) with peak photosynthetic rates observed at 35°C (Ehleringer, 1983) and intense solar radiation (Jin et al., 2016), while low temperature reduces the vegetative growth (Whitehead et al., 2002).

Amaranth contains an adequate amount of proteins, linoleic acid, and minerals such as iron, magnesium, and calcium in both the grain and leaves (Schnetzler and Breen, 1994; Alvarez-Jubete et al., 2009a,b), which approximately 40%-50% higher than other staple crops including corn and rice, also 5%-10% higher than other leafy vegetables such as spinach and chard (Rastogi and Shukla, 2013). The grain is gluten free (Alemayehu et al., 2014), so it can be used in the diets of people with celiac disease (Pastor and Ačanski, 2018). The protein consists of high levels of the amino acid lysine, which are lacking in maize, wheat, and rice (De Ron et al., 2017) (Table 6.1). The sulfur-containing amino acids, normally limited to beans and other legumes, are also high in grain amaranth, and it is ranked second for protein quality after soybean (*Glycine max*), and approximately 50% higher compared to wheat, rice, and maize, with range of 12.0%−22.5%, (Gupta and Gudu, 1991; Schoenlechner et al., 2008). In addition, the lipid content of grain amaranth including fatty acid, triglyceride, and sterols are two- to threefolds higher than in buckwheat and other common cereals, and 50% of the fatty acids are made up of unsaturated linoleic acid (Alvarez-Jubete et al., 2009b, 2010).

Vegetable amaranth is an excellent source of vitamin A, carotenoids, ascorbic acid, phenolics, and riboflavin, with a cup serving contributing up to 34% of the daily value of magnesium and up to 60% of the daily value of vitamin C (Jiménez-Aguilar and Grusak, 2017) (Table 6.2).

TABLE 6.1 Comparison of grain amaranth with other grains (per 100 g) (USDA and National Research Council) (Rastogi and Shukla, 2013).

Component	Amaranth	Corn	Rye	Buckwheat	Rice
Protein (%)	14.5	9	13	12	7
Lysine (%)	0.85	0.25	0.4	0.58	0.35
Carbohydrate (g)	63	74	73	72	71
Calcium (mg)	162	20	38	33	41
Iron (mg)	10	1.8	2.6	2.8	3.3
Phosphorus (mg)	455	256	376	282	372

TABLE 6.2 Comparison of nutrient components of vegetable amaranth with other leafy vegetable crops (Rastogi and Shukla, 2013).

Components	Amaranth	Spinach	Basella	Chard
Protein (g)	3.5	3.2	1.8	2.4
Ascorbic acid (mg)	80	51	102	32
Fiber (g)	1.3	0.6	0.7	0.8
Carotenoids (IU)	6100	8100	8000	6500
Fat (g)	0.5	0.3	0.3	0.3
Carbohydrate (g)	6.5	4.3	3.4	4.6
Calcium (mg)	267	93	109	88
Iron (mg)	3.9	3.1	1.2	3.2
Potassium (mg)	411	470	N/A	550

High levels of quercetin glycoside and hydroxycinnamic acid derivative isomers in amaranth leaves further emphasize the health benefits of this crop (Neugart et al., 2017). There is wide genetic variation and large genotype to genotype differences for these nutritional traits (Srivastava, 2011), which could provide considerable material for future breeding program to improve human diet (Shukla et al., 2010; Sarker et al., 2014; Neugart et al., 2017; Shukla et al., 2018). Being a cheap source of vitamins, vegetable amaranth could be among the crops needed to achieve the objective of the United Nations Sustainable Development Goal 2 (Zero Hunger), which is to eradicate malnutrition and to implement resilient agricultural practices, particularly in South East Asia and sub-Saharan Africa.

6.3 Past research at a glance

6.3.1 Genetic diversity

Correct genotypic identification and preservation of genetic variation are important to maintain ecotypes that have desired traits for breeding programs (Perez-Gonzalez et al., 2001). Amaranth has high phenotypic plasticity and a large amount of genetic diversity (Rastogi and Shukla, 2013), and therefore it is important to characterize the amaranth germplasm, recognize its redundancy, and identify intramorphyte variation among the amaranth genotypes (Jimenez et al., 2013).

In the past decade, several biochemical and molecular markers have been developed for genome evolutionary and phylogenetic relationship between grain amaranth and its putative weedy progenitor, including allozyme markers (Hauptli and Jain, 1984), isozymes (Chan and Sun, 1997), random amplified polymorphic DNA (Popa et al., 2010; Mandal and Das, 2002; Transue et al., 1994), amplified fragment length polymorphism (Oduwaye et al., 2014; Štefúnovà et al., 2014; Costea et al., 2006; Wassom and Tranel., 2005; Xu and Sun, 2001), inter simple sequence repeat (Raut et al., 2014); simple sequence repeat (Kietlinski et al., 2014; Suresh et al., 2014; Khaing et al., 2013; Oo and Park., 2013; Wang and Park, 2013; Lee et al., 2008; Mallory et al., 2008) and SNPs (Wu and Blair, 2017; Stetter et al., 2016; Jimenez et al., 2013; Maughan et al., 2009), bacterial artificial chromosome library (Maughan et al., 2008), genetic maps (Maughan et al., 2011), transcriptome (Liu et al., 2014; Sunil et al., 2014; Delano-Frier et al., 2011; Riggins et al., 2010), chloroplast genomes (Chaney et al., 2016), low-copy nuclear loci and chloroplasts regions (Waselkov et al., 2018), and draft genome assembly (Lightfoot et al., 2017; Clouse et al., 2016; Sunil et al., 2014). However, to date, there are few corresponding markers available for vegetable amaranth species.

The majority of markers listed earlier detected high levels of genetic variation within and among amaranth species and admixed accessions, with no specific geographical origin or morphological stratification (Jimenez et al., 2013).

Nevertheless, with the recent use of SNPs discovery, Genotype-by-Sequencing (GBS) has proved to be an efficient method to determine the genetic diversity of grain and wild amaranth accessions with consistent geographical origin and morphological classification as well as to validate phylogeny of the *Amaranthus* genus (Stetter et al., 2017; Wu and Blair, 2017). GBS was only applied to amaranth once the reference whole-genome sequence of *A. hypochondriacus* was published, representing the closest genus among *Amaranthus* spp. (Clouse et al., 2016; Lightfoot et al., 2017). This approach has identified SNPs that captured most of the genetic variation in amaranth that will aid breeders to efficiently tap the available sequence diversity and generate significant data on the genetic control of traits to create improved cultivars.

6.3.2 Whole-genome sequencing

The draft genome of amaranth (*A. hypochondriacus*) first produced by Sunil et al. (2014) was highly fragmented, containing 367,441 scaffolds, with a scaffold N50 = 35 kb, and was 40% larger than the predicted genome size of 431.8 Mb (Bennet and Smith, 1991) or approximately 500 Mb (Lightfoot et al., 2017). The latest high-quality reference genome (*A. hypochondriacus*) produced by Lightfoot et al. (2017) was highly contiguous, scaffold N50 = 24.4 Mb, with a total sequence length of 403.9 Mb, representing 93.5% of the predicted genome size. This sequence was successfully done using PacBio single-molecule sequencing, Illumina high-throughput reads, and Hi-C-based proximity-guided assembly of the $n = 16$ haploid chromosomes. The assembly of the 16 chromosomes with a size range of 17.0−38.1 Mb provides a remarkable anchor for SNP loci and allele sequences discovered here. This genome assembly confirmed that *Amaranthus* spp. genus underwent whole-genome duplication before speciation, which was then followed by further duplication, chromosome loss, and fusion events (Behera and Patnaik, 1982; Lightfoot et al., 2017; Stetter et al., 2017; Stetter and Schmid, 2017).

6.3.3 The functional basis of drought tolerance

Plants have various mechanisms to withstand drought stress, and understanding the genotypic differences in vegetable amaranth in response to water deficit is crucial if new breeds and cultivars are to be developed. It is worth exploring multiple factors that are involved in drought stress before establishing a reliable screening method for the large-scale selection, or for breeding stock. This is because screening for drought surrogate traits require large amounts of space, time-consuming, expensive and inadequate seed availability of certain genotypes in early generations (Hura et al., 2007).

Amaranth species have a high water-use efficiency allowing them to withstand periods of water deficit, partly due to their C_4 photosynthesis (Lal and Edwards, 1996; Liu and Stützel, 2002a,b; Omami and Hammes, 2006). Amaranth displays a high transpiration rate compared with C_3 plants (Jamalluddin et al., 2018) and is able to maintain transpiration at early drought stress and hence, the capacity to keep assimilating CO_2 until the drought becomes severe (Slabbert and Krüger, 2011). Amaranth has also been reported to reduce its total leaf area through inhibition of cell expansion and leaf senescence under drought stress (Luoh et al., 2014).

Other factors that may influence water efficiency in amaranth is that amaranth belongs to the NAD-ME subtype of C4 plants (Ueno, 2001; Babayev et al., 2014), together with switchgrass (*Panicum virgatum* L.) and pearl millet [*Pennisetum glaucum* (L.) R. Br]. These crops occur more frequently in dry areas (Taub and Lerdau, 2000). Wild amaranth species, including *A. hybridus*, *A. powellii*, and *Amaranthus retroflexus*, have been shown to have high rates of photosynthesis and rapid growth rates in drier conditions, and have a tendency to become invasive in a globally warming climate, competing for resources with cultivated crops (El-Sharkawy, 2016). NAD-ME plants exhibit superior water-use efficiency under drought conditions due to its leaf structure and faster leaf curling rates (Ghannoum, 2009; Liu and Osborne, 2015). The highly elastic leaf characteristics provide a large capacity to deviate from an ideal osmotic system, which may buffer transient changes in transpiration and contribute to water storage for survival after stomata closure (Bartlett et al., 2012; Sack et al., 2013). In amaranth, the association of leaf structural traits with the photosynthetic rate was only studied under normal conditions by Tsutsumi et al. (2017). The structural traits of the leaves such as stomatal density, guard cell length and leaf thickness, interveinal distance, and sizes of mesophyll and bundle sheath cells were not significantly correlated with the rate of photosynthesis in amaranth. Nevertheless, these adaptive traits could play a key role in plant survival under drought stress, for example, increased stomata density during short-term water stress (Franks and Farquhar, 2007), longer and narrow leaves to stimulate faster leaf curling rates to save water, and high lower leaf cuticular conductance to provide higher internal resistance (Sack et al., 2013). Meanwhile, many kinds of cereal belong to the NADP-ME subtype, including maize, sugarcane (*Saccharum* spp.), and sorghum (*Sorghum bicolor*) (Edwards and Walker, 1983), which exhibits better nitrogen use efficiency (Liu and Osborne, 2015).

It is not known which enzymes are rate-limiting factors in NAD-ME type C_4 photosynthesis, but in amaranth, it may be Rubisco (von Caemmerer and Furbank, 2016; Tsutsumi et al., 2017). This is due to several findings including the formation of a new isoform that contributes to the accumulation of CO_2 in bundle sheath cells (Babayev et al., 2014).

As a C_4 crop, the reduction of photosynthesis in amaranth is less likely to involve stomatal conductance, but rather a nonstomatal photosynthesis limitation, which is related to photoinhibition injury of the photosynthetic apparatus, and disturbance in the enzymatic process of photosynthesis. This photoinhibition has been seen in amaranth, where small changes in leaf water potential induce small changes in stomatal conductance, resulting in the accumulation of intracellular CO_2, which then results in photodamage of PSII reaction centers (Baker and Rosenqvist, 2004; Slabbert and Krüger, 2011).

Photoinhibition is severe in green leaves compared to red. This is due to the presence of the main betacyanin pigment in amaranth, that is, amaranthine that contributes to the red or purple color of the plants and has potential as an antioxidant due to its abundance of hydroxyl and amino groups (Cai et al., 1998; Strack et al., 2003). Red leaves display high maximum quantum efficiency of PSII photochemistry (Fv/Fm) and photochemical quenching coefficient during water stress with an increased relative abundance of betacyanin to chlorophyll content (Shao et al., 2013). This increased betacyanin contributes to the increased total photoprotective capacity by lowering excitation pressure on PSII via attenuation of potentially harmful excess incident light under water stress in amaranth (Nakashima et al., 2011).

Tolerance of amaranth is also dependent on its osmoprotective regulation, cellular protecting mechanisms, and restoration of damage capabilities. In amaranth, antioxidant enzymes such as superoxide dismutase, APX, and glutathione reductase are increased under drought stress (Slabbert and Krüger, 2014), and this plays a crucial role in tolerance of vegetable amaranth (Sarker and Oba, 2018). These enzymes scavenge highly reactive oxidative stress, that is, reactive oxygen species (ROS) during drought stress and thus protect plants organelles particularly photosynthetic apparatus, lipids, proteins, and nucleic acids (Rout and Shaw, 2001) from oxidative damage and photooxidation caused by ROS activity (Wang and Park, 2013).

6.4 Nutritional security in the face of climate change

Plants require 14 essential mineral nutrients including nitrogen, phosphorus, and potassium to build up structural components of numerous macromolecules including nucleic acids, phospholipids, certain amino acids, and several coenzymes (Grusak, 2001; Marschner, 2012). These mineral nutrients are also involved in chlorophyll biosynthesis, redox reactions, plasma membrane integrity, which is required in the regulation of osmotic potential of cells (Nakandalage and Seneweera, 2018). Under a changing climate, soil nutrients may become poorly available especially in arid and semiarid areas where water availability is dependent on unpredictable rainfall, and this may impact the accumulation of minerals and proteins required for the growth of crop plants (Soares et al., 2019). Therefore preserving the nutritional quality of crop plants under a changing climate is necessary to ensure that the world's growing population has secure access to plentiful, safe, and nutritious food.

Notwithstanding, vegetable amaranth still provides substantial amount of micronutrients such as minerals, vitamins A and C under drought stress as cell protection systems stimulate the synthesis of secondary metabolites such as phenolics and flavonoids to overcome oxidative damage of ROS activity (Sarker et al., 2018). In fact, drought stress significantly increased nutritional and bioactive compounds, including protein, ash, energy, fat and dietary fiber content, phenolic acids, flavonoids and antioxidant capacity with the increased drought severity, although the accumulation of nutritional properties depended on species' plants varieties (Luoh et al., 2014; Jiménez-Aguilar and Grusak, 2017; Sarker et al., 2018). Enhancement of these nutritional elements in leafy vegetables has beneficial effects of reducing the risks of human disease caused by oxidative damage and aging (Iwai, 2008), such as cancer, arthritis, emphysema, retinopathy, neurodegenerative cardiovascular diseases, atherosclerosis, and cataracts (Isabelle et al., 2010; Steffensen et al., 2011), and it is a good weapon to fight hidden hunger (micronutrient deficiency).

Despite the substantial amount of micronutrients, consumption of vegetable amaranth is still low, and the intake is higher in rural than urban areas (Gido et al., 2017a). Reports also show that employed rural dwellers with better income consumed less vegetable amaranth compared with nonemployed people and casual laborers (Kimiywe et al., 2007; Gido et al., 2017b), with the exception of elderly people with an interest in traditional medicinal treatments (Gido et al., 2017a). Similarly, vegetable amaranth and other indigenous vegetables are perceived as poor people's food by the wealthier and urbanized dwellers (Frazao et al., 2007; Jan van Rensburg et al., 2007; Faber et al., 2010). However, there is evidence to suggest that diversifying our food basket with indigenous vegetable crops including amaranth and making these available at retail markets could attract more consumers in both rural and urban areas (Gido et al., 2017a). Making a wider range of food crops available to people could, therefore, increase the diversity of food sources and dietary options and increase the consumption of nutritious foods leading to better nutrition outcomes. Therefore further interventions including promotion and raising awareness of its nutritive value are needed to raise consumption levels of this nutritious vegetable especially in urban areas, where leafy vegetable consumption is currently low.

Dietary nitrate is growing in popularity as a sports nutrition supplement as it can increase endurance during exercise (Tarkin and Kaski, 2016). As a member of the Amaranthaceae family, amaranth belongs to nitrate-accumulating vegetables, together with two other families, Brassicaceae (rocket, radish, mustard) and Chenopodiaceae (beetroot, Swiss chard, spinach) (Santamaria, 2006). Although nitrate was known as antinutritional compound and often associated with harmful effects on human health such as methemoglobinemia in infants (blue baby syndrome) (Fan and Steinbers, 1996; Knobelock et al., 2000), and gastroenteritis in adults (Spiegelhalder et al., 1976; Lundberg et al., 2009), appropriate amounts of nitrate consumption (averaged of 106 mg) can give beneficial effect on individuals, especially in high-performance athletes (Lundberg and Govoni, 2004; Hord et al., 2009; Jonvik et al., 2017). Nitrate itself is nontoxic, but the reaction with anaerobic bacteria in saliva and gastrointestinal acid converts approximately 20% ingested nitrate into toxic nitrite, which is further converted to nitrosamine that has been found to elicit carcinogenesis and stimulate nitrate-related diseases. However, in low oxygen availability, nitrate is converted to nitric oxide, which reduces the oxygen cost of submaximal exercise, which has an advantage on vascular and metabolic control (Jones, 2014). High nitrate content in the vegetable can be found in the petiole, followed by leaf, stem, root, inflorescence, tuber, bulb, fruit, and seed (Maynard et al., 1976; Santamaria et al., 1999). The nitrate accumulation in amaranth leaves increased with increased application of nitrogen fertilizer (Onyango et al., 2012); similar results have been reported in lettuce and spinach leaves (Szwonek, 1986). However, C_4 plants, in general, have shown that nitrate assimilation and nitrate uptake reduced under water stress (Foyer et al., 1998; Ghannoum, 2009), which could be due to decreased chlorophyll and protein content (Carmo-Silva et al., 2007). Nevertheless, under normal conditions, healthy vegetable amaranth consists of high levels of nitrate compared to lettuce, beetroot, and spinach (Jana and Moktan, 2013; Gorenjak and Cencič, 2013); therefore amaranth is a good vegetable for healthy living and may support better exercise performance. This clearly requires further research and could broaden the potential consumption of vegetable amaranth and attractiveness to consumers and the food industry as a crop beyond food and nutrition security.

The leaves of vegetable amaranth contain antinutritional compound oxalate and are therefore in general not consumed raw (Vityakon and Standard, 1989). In plants, oxalates are known to regulate calcium in cells (Faheed et al., 2013), and they have a protective role against insects (Korth et al., 2006). However, human oxalates interfere with calcium bioavailability, and therefore ingesting large amounts of raw amaranth leaves would result in a reduction of calcium availability, both in the amaranth leaves themselves and from other food sources eaten simultaneously (Vityakon and Standard, 1989). In addition, consumption of large quantities of foods rich in oxalate can result in the production of calcium oxalate, which can cause digestive disorders and kidney damage (Noonan and Savage, 1999). Accumulation of oxalate appears to increase with the age of the leaves (Yoshikawa et al., 1988), so eating young raw amaranth leaves is less of a barrier to consumption than older leaves, which must be cooked. Several studies have suggested that oxalate accumulation can be manipulated by nitrate and ammonium application (Cai et al., 2018; Liu et al., 2015). For example, spinach plants treated with NO_3^- were found to accumulate higher levels of oxalate in the leaves than plants treated with NH_4^+ (Liu et al., 2015; Proietti et al., 2004). Similar results have been observed in *A. tricolor* and *A. cruentus*, where oxalate accumulation was significantly and differentially affected by the application of different levels of an NPK and an organic manure fertilizer (Tabitha et al., 2018). Oxalate levels have not been extensively studied in vegetable amaranth; however, genotypic differences have been observed in several grain amaranth species (Gélinas and Seguin, 2007). A combination of selective breeding and crop management could, therefore, be used as part of a successful amaranth genetic improvement strategy to reduce oxalate content in leaves. Making low oxalate vegetable amaranth available for consumption would introduce the crop to new consumer markets and broaden its appeal in existing markets.

As with many vegetables, leafy amaranths are highly perishable due to high moisture content (Makabo et al., 2010). Loss of more than 3% of the original fresh weight due to wilting and senescence leads to poor quality produce and loss of vitamin C (Ben-Yehoshua and Rodov, 2002). Extra care during postharvest and pretreatment including suitable packaging are therefore needed to retain freshness, extend shelf life, and maintain color and natural fresh taste. Low-cost storage such as evaporative cooling technologies that require no electricity can retain freshness up to 3–5 days and are affordable for the resource-poor smallholder farmers (Ambuko et al., 2017). However, the adoption of such technologies is still low among smallholder farmers.

6.5 Prospects for future research

Developing breeding programs for underutilized crops begins with cultivar development based on consumer preference, adequate adaptation to various environmental conditions, long shelf life, superior taste, high nutrition, and affordability (Afari-Sefa et al., 2012; Sogbohossou and Achigan-Dako, 2014). The identification of product targets requires proper strategy in collecting and characterizing germplasms, which is the primary step for the exploitation of genetic diversity and to acquire desired traits, and the genomic tool can accelerate the entire development of cultivars (Brandolini et al., 2000; Perez-Gonzalez et al., 2001). Although amaranth has a substantial amount of genetic diversity (Rastogi and Shukla, 2013), the characterization of the amaranth germplasm is still lacking, and the utilization and management mainly depended on resources available in the selected ex situ conservations (Khaing et al., 2013; Stetter et al., 2017). Breeding programs for amaranth are still at an infant stage and will require concerted efforts and funding to support research and development to elevate amaranth out of underutilization (Brenner et al., 2010; Alemayehu et al., 2014; Stetter et al., 2016).

Several efforts have been implemented to characterize amaranth germplasm using morphological markers, including plant height, leaf color, and stem diameter (Wu et al., 2000; Oboh, 2007; Pandey, 2009; Shukla et al., 2010; Akther et al., 2013; Selvan et al., 2013; Gerrano et al., 2017). Morphological markers are the primary sources of genetic diversity, and specific traits such as shape, size, and color of the leaf, stem, inflorescence, and seed are fast and easy to assess for direct use by farmers and are of great help to plant breeders when selecting potential parental lines (Krichen et al., 2012; Sarker et al., 2014). For example, plant height, number of branches, and total leaf area are the most potentially useful morphological traits for high yield in vegetable amaranth productions (Sogbohossou and Achigan-Dako., 2014). Whereas, stem and leaf color of amaranth demonstrate variations in drought tolerance characteristics (Nakashima et al., 2011) and reported to have high variability and heritability compared to other morphological traits (Gerrano et al., 2006, 2017; Ahammed et al., 2013; Sogbohossou and Achigan-Dako, 2014; Thapa and Blair, 2018). The high degree of morphological variations observed in amaranth may be beneficial in terms of its adaptive capabilities in different climatic conditions. Andini et al. (2013) attributed the high morphological variations to polyploidy, while Kulakow and Hauptli (1994) reported the mixed-mating system of amaranths that may facilitate the natural introgression process as a contributing factor. A lack of selection pressure has also been implicated (Chan and Sun, 1997).

Morphological traits as markers have played a big role in genetics, breeding, and conservation of genetic resources. However, an evaluation of genetic diversity based on morphological traits alone is not enough to make sufficient improvement in characterizing amaranth germplasm, as amaranth has high phenotypic plasticity, which is highly influenced by environmental effects (Banerjee and Kole, 2009; Tabatabaei et al., 2011). Therefore combined analysis using morphological and molecular markers is needed to produce more accurate data on genetic distances and genotype and environment interactions (Malviya et al., 2012).

Vegetable species of amaranth have been studied less by molecular means, compared to pseudocereal grain amaranths as well as weed species, especially when both are phylogenetically related and the occurrence of domestication events between them were proven (Mallory et al., 2008; Khaing et al., 2013; Stetter et al., 2017, 2015). Also, to date, very little information is available on the genetic diversity of leafy amaranth vegetable, especially *A. tricolor*, the most cultivated species, with only five or fewer accessions included among other amaranth species in any molecular approaches, including SSR (Khaing et al., 2013) and GBS (Stetter and Schmid, 2017).

Genotyping by molecular markers is very valuable for genetic identification and diversity, which can lead to the discovery of novel alleles, useful in breeding programs (Nadeem et al., 2018). Therefore the genetic diversity studies of vegetable amaranth together with grain and weed amaranth should be improved so that it can provide insights on the key genetic basis of drought tolerance traits in vegetable amaranth. The genome of amaranth is relatively small (500 Mbp) and diploid, making it easy to study potential genetic constraints for domestication as well as drought tolerance traits (Stetter et al., 2017; Stetter and Schmid, 2017). The rapid advance in next-generation sequencing technology has reduced the genotyping prices and allows for wide utilization of the GBS platform to genotype any crops and whole collections within genebanks (Elshire et al., 2011). GBS offers a number of advantages, as it is more practical, inexpensive and has driven genotyping to be applied to nonmodel organisms, does not require a reference genome (Elshire et al., 2011; Andrews et al., 2016). It has been successfully applied in many underutilized crops including teff (*Eragrostis tef*) (Cannarozi et al., 2014) and has been used in the cross-species comparison between bambara groundnut (*Vigna subterranea* L.) and common bean (*Phaseolus vulgaris*). The use of GBS platforms has been shown to be the most efficient method for high-throughput genotyping in amaranth (Stetter and Schmid, 2017; Stetter et al., 2017; Wu and Blair, 2017). *A. tricolor* genome has not yet been sequenced; thus a genetic improvement in agronomical traits can only be carried out using reference genome of closely related species, *A. hypochondriacus* (Lightfoot et al., 2017) or other closely related genera.

Drought stress tolerance and water-use efficiency are one of the main strengths of this crop, and an understanding of the mechanisms and traits that confer drought tolerance is crucial. Ideally, the measurement of the target traits should be nondestructive, rapid, accurate, and inexpensive (Tuberosa, 2012). The key criteria for the development of rapid screening methods are that the technique used must be capable of evaluating plant performance at critical stages of development, use a small amount of plant material, and be able to screen a large number of plant varieties in short time as possible (Johnson and Asay, 1993). The screening methods should fulfill important requirements for drought tolerance in individual crop plants, which can then be incorporated in breeding programs to facilitate significant genetic gains. To date, only a few studies have been carried out to identify surrogate traits in vegetable amaranth, including water-use efficiency (Jamalluddin et al., 2018) and ROS marker and biochemical parameters (Sarker and Oba, 2018). A rapid drought screening method for vegetable amaranth is yet to be developed. It is clear as reported previously that there are substantial drought effects on the measured parameters with significant and differential genotype responses, which are dependent on the degree and duration of drought stress. Few

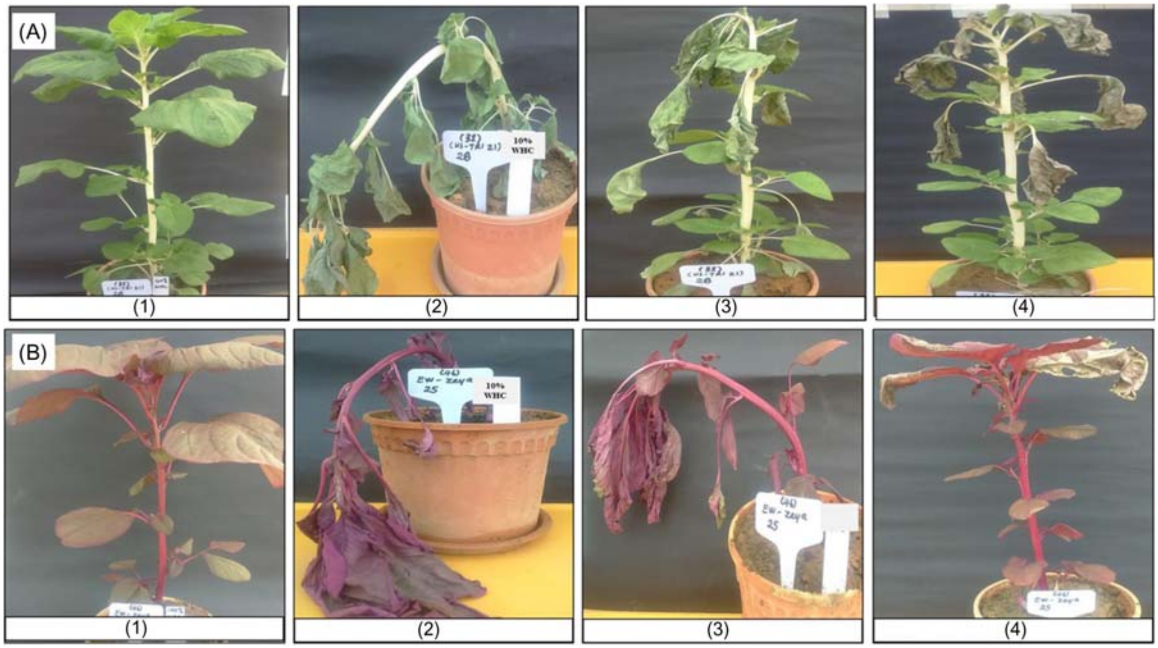

FIGURE 6.2 The example of rapid screening method, that is, rewatering assessment on vegetable amaranth genotypes. Physiological parameters including days of wilting, wilting scoring, and days of recovery were recorded on (A) green leaf *A. tricolor* and (B) perfect red *A. tricolor*. The images were captured (1) on a day before the imposition of drought stress (100% water holding capacity), (2) at terminal drought stress (10% WHC), (3) 24 hours after rewatering, and (4) 72 hours after rewatering.

studies have also been carried out in grain amaranth, which can be adapted for use in vegetable-type amaranth to find surrogate traits for drought tolerance (Liu and Stützel, 2002a,b, 2004; Hura et al., 2007b; Babayev et al., 2014; Luoh et al., 2014; Slabbert and Krüger, 2011, 2014; Jomo et al., 2016; Tsutsumi et al., 2017).

Different physiological parameters have been shown to be an effective tool for indirect selection for yield under drought stress in various major crops (Fig. 6.2). For instance, screening of deep and vigorous root system for higher yield under drought stress has been recognized in many crops such as wheat (Wasson et al., 2012), soybean (Sadok and Sinclair, 2011), and rain-fed rice (Henry et al., 2011). Although larger root systems promote greater water uptake, which leads to high productivity under water-limited conditions for specific crops variety, restrictions in regulations of water uptake may be more strategic for a plant to manage limited water availability (Vadez, 2014) as occurred in upland rice (Singht et al., 2017). This is because a large root system would consume more photosynthetic end products for their own growth and negate shoot growth (Bramley et al., 2009). Other than modifying root systems, maintaining high photosynthetic rates (Wang et al., 2016), or accelerating chlorophyll decompositions (Chen et al., 2016) under drought stress, can be a good predictor for indirect selection of drought-tolerant genotypes. In addition, biochemical analysis such as proline contents has been used as a complementary strategy for a selection of high yielding genotypes under drought stress (Bowne et al., 2012; Mwadzingeni et al., 2016). Accumulation of proline content under drought stress has been associated with osmoprotectant roles such as osmotic adjustment and membrane stabilization and activates antioxidant defense mechanisms in amaranth (Slabbert and Krüger, 2014).

6.6 Conclusion

Amaranthus spp. has been a source of nutritious food for many centuries in Africa, Asia, Central, and South America. It is now being consumed and cultivated worldwide and is a promising health food and climate-smart crop. It has the potential to alleviate poverty, malnutrition and diversify our food sources to minimize risks associated with our reliance on only a few staple crops in the face of increasing global droughts. With a wide genetic base and better tolerance to drought stress, amaranth provides a new prospect in the development of new crops for nutritional security. However, the genetic material is poorly characterized. Therefore a proper characterization of amaranth germplasm through a combination of physiological, morphological, and molecular data and their association with drought tolerance traits are needed in order to develop a framework for future breeding programs.

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CHAPTER

7

Metrics for identifying food security status

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7.1 Introduction

7.1.1 Evolving concept of food security

7.1.1.1 Beginning of food security definition

Food security began getting mentioned in the early years of 1970s, and was defined along the concept of "food supply" (Simmons and Saundry, 2012). Those times had stiff food crises where the greatest concern was of the global political instability as a result of acute shortage of food supplies. At that moment, scientists discovered that food availability was affected, and the community households could hardly get accessed to food (Jones et al., 2013). Thus food availability had then served a great deal in describing the pathways of food system and sustainability.

Food accessibility, which is the second domain of food security, was put on limelight by Amartya Sen, the Nobel Laureate. In his 1981 thesis entitled, "Poverty and Famines: An Essay on Entitlement and Deprivation," Sen emphasized the usefulness of food access as an embodiment of food security, and as a compulsory domain (Sen, 1981). However, food security is never constant in its accessibility. It often varies with the spread of time either in different seasons or as effects of weather irregularities, deaths, political crises, and/or regional conflicts (Barrett, 2010). So, Sen went further to bring on light the discoveries from the past famine experiences of the countries that drove them to harbor sufficient food for supply afterward for the citizens.

In the same paper, Sen noted that the poor were vulnerable, being readily edged off food entitlements due to hiked up prices of food owing to their low wage rate. So, even if food supplies were equally sufficient, it would be of less help to the poor who choked in their low incomes. Because these group have a cycle of hand-to-mouth living, they hardly have additional money to cater for hiking rates of food. They basically spend a bigger pie of their household income on food while relying on their labor efforts for main income acquisition (Jones et al., 2013). Therefore the vulnerable group were mostly hampered from an easy access to available food, and food security would not further be defined on a concept of "food supply" alone.

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7.1.1.2 *Inclusive elements of food security*

The World Food Summit, in 1974, adjusted the definition of food security to "the availability of adequate world food supplies at all time." This definition had been remodeled in the shift of thinking provided by Sen in 1983 (Jones et al., 2013). This definition saw the revision of food security so as to include aspects of physical and economical abilities of the individuals to access food. Food security definition had then transformed to "physical and economic accessibility of food at all times."

The 1983 World Food Summit's definition of food security was not the end of its definition (the evolution went on). Concerns on inequitable distribution and food accessibility to households grew another definition expected to be all-inclusive. Jones et al. (2013) sets an example from the past studies and postulates that data analyses on behaviors of in-households had indicated that women allocated expenditures that favored nutrition, health investments, and children education, among others. Furthermore, it was evident that parents had no identical preferences toward the male and female children. Thus another important element determined here to be a part of food security was "household food acquisition behaviors."

According to Haddad et al. (1997), food acquisition behaviors had full influence on physical and economic food accessibility, and it is a determining factor of food security. In fact, Jones et al. (2013) back this up stating that those findings had later contributed to the biased preference of "collective" approaches, which is household decision-making modeling, instead of "unitary" approaches, which is a unison form of making decisions by the household.

Jonsson (2010) notes that the mid of 1990 brought in a nutrition-focus objective that aimed at alleviating micronutrient deficiencies (majorly iron, vitamin A, and iodine). This meant a shift from mere fulfilment of caloric sufficiency to overall diet quality. A whole new concept of household food security came in by the "utilization" discovery. This was the component or domain that portrayed nutrition attributes of the food security. Utilization simply enlightened the nutritional make-up of individuals. Therefore it was brought in as the third domain of food security considering sufficient nutrient absorption and assimilation in an individual body to an ability of impacting change in health (Jones et al., 2013).

Utilization is based on food allocation within households, the nutrient dense of the food, and degree of metabolism and nutrient absorption by individual members of the household based on differences in members' health status or micronutrient bioavailability. This science-based discovery led delegates to further revise food security definition at the 1996 World Food Summit. It had noted the benefits of a diet quality on both individuals and households.

7.1.1.3 *Food and Agriculture Organization 's overall definition of food security and metrics derivation*

In 1996 the World Food Summit (accorded by FAO) defined food security as: "Food security, at the individual, household, national, regional and global levels is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." This definition provided, on the other side, that food insecurity is the absence of one or more of the detailed food security aspects. Elliot Vhurumuku (2014) captions this definition given by FAO (1996) as "a state when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life."

Aside from the aforementioned three domains of food security, that is, availability, access, and utilization, there are external factors affecting the population's food security status such as socially and culturally accepted foods. These factors complete the entire eco-identification of the food security concept. And, the concept "at all times" advocates for the fourth and less sensed domain of food security—food stability. Pinstrup-Andersen (2009) states that the comprehensiveness of food security definition has raised questions as to whether specifying concepts into their component definitions and severity extent may be necessary for the purpose of guiding policies and programs toward appropriate solutions of different food security challenges.

The evolution of food security definition has been based on field of thoughts and ideas guiding standardization of metrics for identifying food security status. By evaluation, food security is the very vital theme that relates to human population, societal development, and research emanating from bettering them.

This chapter may have not featured all the metrics of food security, but has at least covered the most current of them. These have been described side-by-side with the domains of food security because metrics and indicators will always incline to these domains.

7.2 Metrics definition

7.2.1 Overview of metrics

Generally, metrics refer to the measures of quantitative features that are assessed in an objective-oriented survey of a study. These measurements include the critical assessments, comparability, and tracking of performance or production. Numerous data content obtained from the field are guided by a process of diverse methods that aim at efficiency. However, different studies have adopted different sets of metrics that correspond to a comprehensive research process. Individual cases of these research findings will therefore guide what type of metrics to be used.

This individual definition however does not lock out other array of definitions from which metrics are described. For instance, the Business Dictionary explains metrics as the standards of measurements where efficiency, process, progress, performance, plan quality, or product can be determined. The Merriam-Webster captures almost the same definition as of Business Dictionary that, metrics is a standard of measurement. Cambridge Dictionary on the other side distinguishes metrics as a set of numbers that give information about a particular process or activity. Several other definitions of metrics have also been provided by specific studies that have managed to implore critical elements of metrics, for example, Gustafson et al. (2016) study briefly covered in Section 7.2.3.

7.2.2 Why is metrics application useful?

Stanford University provides significance of applying metrics in any meta-research done. They depict that the main objective of a research guide metrics is to realize the most comprehensive findings and to draw an all-inclusive conclusion. This way, metrics promote research and allow for innovation in five basic areas that are described in the following.

1. *Designing and conducting research*: involves developing an objective-oriented questionnaire and an appropriate study design, conducting the study, statistically analyzing data obtained, and interpreting the findings. The researchers tend to identify the biases and flaws of the study from this phase and develop necessary methods to counter them after testing. Then they suggest the practices of best fit.
2. *Communication*: involves reporting of a research work through precise-written research papers where a vast number of audiences are reached. The results obtained from the researchers' studies form a platform for feeding or recommending further research works. Communication of results therefore performs a linking function between the researchers and those who need further explorations from the results.
3. *Evaluation*: with appropriate metrics, scientific quality can be evaluated continuously for funding decisions, journal publications, medical practices, academic promotions, policy setting decisions, and industry investments among others.
4. *Verification*: scientific credibility will majorly depend on replication of the research results, and thus an accurate reporting and best peer-review practices provide rationale for effectiveness and usability of research results. Verification should be more routine and effective.
5. *Reward*: research work is a rewarding activity by itself. If well processed, it creates a cloud for its continuity through recognition, funding, and career advancement to be determined as a successful work in the science fraternity.

7.2.3 Evaluating food metrics by food systems

Metrics provide an opening for a given goal and align to the Sustainable Development Goals (SDGs) (Gustafson et al., 2016). Preferably, composite metrics is used because it embeds multiple indicators featuring varied algorithmic sequences. This way, indicators refer to either quantitative or qualitative aspects capturing the changes in the system that occur after a simple and reliable-based intervention (Bach et al., 2008). Eventually, indicators stem up from multiple variables of direct field data collected.

According to Gustafson et al. (2016), food metrics are expressly defined in a seven food system model that include food nutrition adequacy, food affordability and availability, food safety, ecosystem stability, sociocultural well-being, resilience, and waste and loss reduction. With this system, an overall score was derived for each metric with respect to their indicators.

In the metrics of Gustafson et al. (2016), there is also an alignment of indicators that fundamentally determines the "scorability." The real purpose for metrics and its indicators here is to commemorate value that increases validity and reliability of the study. It also means that it is easy to describe what has value than what has a hidden or unknown value. Precision is attained in the order producing efficiency, and necessary formulae can be drawn and standardized for use in all applicable metrics of same themes and nature. Thus indicators provide a base of inculcating scores that are inevitable and predictable in a regular explorative pattern.

Table 7.1 explicitly explores an inclusive set up of food system metrics and their indicators. It features an ideal presentation of metrics formation by Gustafson et al. (2016).

TABLE 7.1 Food system metrics and their indicators.

Metrics	Indicators	Score
Food nutrition adequacy	Nonstaple food energy Shannon diversity Modified functional attribute diversity Nutrient density score Population share with adequate nutrients	
Food affordability and availability	Food affordability GFSI food availability score Poverty Index Income equality	
Food safety	Foodborne disease burden GFSI food safety score	
Ecosystem stability	Ecosystem status Per-capita greenhouse gas emissions Per-capita net freshwater withdrawals Per-capita nonrenewable energy use Per-capita land use	
Sociocultural well-being	Gender equity Extent of child labor Respect for community rights Animal health and welfare	
Resilience	ND-GAIN Country Index Food production diversity	
Waste and loss reduction	Pre- and postconsumer food waste and loss	

GFSI, Global Food Security Index; ND-GAIN, Notre Dame Global Adaptation Index.
From David et al. (2016).

A focused orientation on food system metrics is meant to open up the hidden concepts surrounding food security. Based on law of ecosystem, food security does not exist on its own but is safeguarded by the constancy of nature and human conservatory mechanisms with their relations. Therefore the metrics of food security is a whole bunch of the components of ecosystem, human practices, and relations on top of food sufficiency. Full description and evaluation of these components attribute to metrics of any study done on food security status.

The selection of metrics for a study is solely dependent on numerous factors such as the target groups (whether farmers, children, adults etc.), environment (whether rural or urban), type of food, and methods of farming among others. Modern researches on food security have preferably selected to quantify data to depict numbers rather than guesses. There are however challenges when dealing with numbers only, and this is the reason to why most research stem up their quantitative research with qualitative analysis that bridges the gaps between numbers and qualitative depictions.

7.3 Describing the existing food security metrics

7.3.1 The pillars of food security and metrics formation

Food security metrics focus mainly on the four pillars of food security. These pillars include food availability, food accessibility, food utilization, and stability. Several studies have chosen to combine these domains in conjunction with the environmental and political factors for standard metrics. Targets for which to collect data may vary broadly from national, regional, household, and even to individual levels, or can be two or more. The tools may be of simple indicators (quick to be collected and easy to analyze) and of comprehensive measurement (intensive in data collection, detailed, and relatively sophisticated in analysis) (Jones et al., 2013). A standardized measurement concretizes tools used for a universal usability or acceptability. Fig. 7.1 displays the metrics derived from the pillars of food security and the associated indicators and factors.

Food security measurement is completed determinably at individual nutritional status. It is not from blues is nutritional status derived but it follows a chain of food security domains and the factors surrounding their flow such as climate, infrastructure, policies, household resources, knowledge, culture and beliefs, sanitation, social programs and dynamics, disease status, life stage, and physical activities among others (Jones et al., 2013).

Every pillar should involve a complete assessment that in detail describes the state of food among the population, households, and basically individuals. For instance, food availability should reflect the source (whether farmed, or market obtained). The source from which food is availed to the household is as well a determination of poverty level among the households in association with other parameters to assess. In addition, food availability is determined from different levels such as from household level or commercial or industrial level. Here we exercise the evaluation of whether the foods are genetically modified, or processed, or are raw from the farms. Nutritional status, as well, is affected by the consumption of foods that are directly obtained from the farm and industries. These also provide a base to assess the diseases that spring up from certain known cancerous foods or other diseases propelled by microorganisms and conditions contrary to the individual body functions. Food availability has many components to be assessed in regard to food security, and these are dependent on specific objectives a study may form. However, a standardization is always provided when the statistical tests of these component achieve significant levels of validity.

Food accessibility involves much of how the food is reached to the unit of food system, which is "an individual" from a household set up. The metric here assesses the distribution methods that will make food physically available to individuals, and also whether it can be accessible economically (affordable). Other elements that reflect the accessibility of food to individuals include; how the safety of

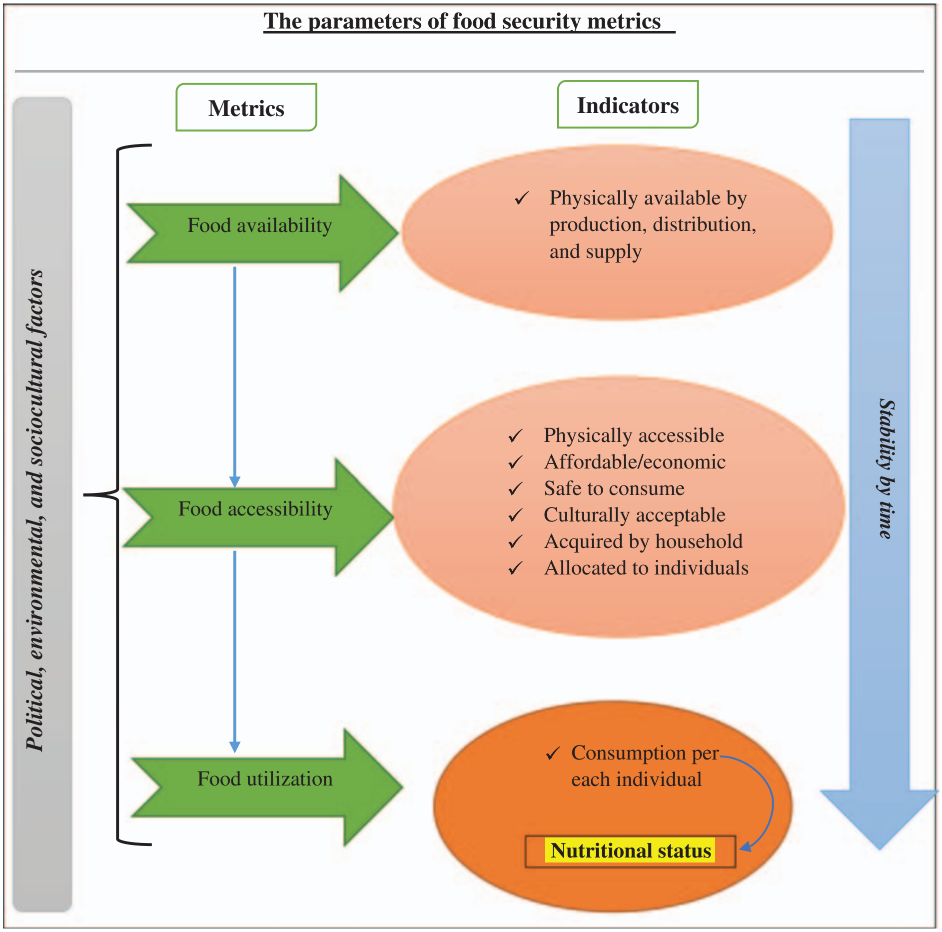

FIGURE 7.1 The pillars defining food security metrics.

food affects food acceptability, and whether the food is culturally accepted by a community or among households. From these elements, metrics here also assess how food will be acquired at the household levels and be allocated to individuals for consumption and assimilation.

Finally, food utilization should be assessed at a nutritional benefit level which accrues to the nutritional status assessment. Here, utilization is assessed in terms of variety, number of members in a household competing for food consumption and any inhibiting factor of food utilization such as acute and chronic diseases. The basis of including food utilization in the food security metrics is to assess and evaluate how food and food practices transform individuals' bodies in a population into good health and dynamic efforts.

These three pillars of food security get consolidated after a long time to produce consistency. This paves way to the last metrics of food security evaluation known as food stability. Food stability is the process of achieving food availability, accessibility, and utilization with time. It is a consistency element of food security. A given household is food-secure based on abilities and measurement of accessing food, obtaining food, and utilizing food efficiently to produce healthy members in the household over a longer time, with little cases of undernourishment or overnourishment in varying seasons of food productions.

Further, the existing metrics of food security provide a probability array on available method options that may not determinably differentiate the conceptualization of food security and neither can specify use of individual tools. Definitely, validity is enhanced when its measurement cannot be separated from the exact purpose it is intended for (Jones et al., 2013). When the metrics chosen are contrary to the intended use, there accrue dire consequences such as:

- measuring variety of units of food security without differentiating between them;
- adopting an inappropriate scale when collecting data;
- measuring a unit of food security that is unintended;
- getting irrelevant information aside from the data required for use;
- mismatching resources required for adequate collection and analysis of data. It may well go beyond the required resources;
- collecting data that cannot be reused in cases of multiple measurement at different interval times.

When these aforementioned consequences remain vivid in the metrics applied, there is a high chance that the results will not be beneficial to providing a regime that will resuscitate a common problem spotted. It may as well mislead the policies formation and any other use it is meant for. Mistakes derived from data collection are likely to shift focus from a real situation to an assumed problem the tools have given birth to. Hence, the whole research is made parallel to the objectives the study intended, and therefore the metrics are wrong and can produce bias and inaccuracies.

7.3.2 Gaps in food security metrics

A need for new metrics is very mandatory for improvement of the current food security measurements. For instance, the measurements of diet quality and sufficiency still give less reliability due to the ineffective approaches applied (are less integral). At the household levels, for example of the rural families, each member recorded different diets consumed in the 24-hour recall. While, when using household dietary diversity score (HDDS), there is variability of a high nature as compared to 24-hour diet recall. This is an issue that requires to be addressed scientifically to consolidate and standardize food security metrics.

Further, apart from diet quality and sufficiency, there is also a need to screen sustainability and efficiency of food systems, and cross-checking with the processes linking the domain's points. These components impact a complete definition of food security, and are highways for metrics and indicators of households' food security. In essence, progress is vital in the six key areas:

1. Measurement of food systems' healthiness. This begins with agriculture to markets to individuals' consumption.
2. Measurement of diet quality.
3. Measurement of people's ability to access adequate and quality food.
4. Improving data on quantity and quality of food taken across population.
5. Measurement of how women's roles impact on dietary choices.
6. Measurement of food environment. This should examine how the food environment interacts one on one with the food system domains and how dietary choices are eventually made in respect to that.

7.3.2.1 *The measure of food system healthiness*

This measurement is meant to examine and sum up the broad concept of sustainability in terms of the sustainable nutrition security (SNS). Simply, this employs diversifying studies of food production and supply by looking at the wing factors that are environmental sustainability and nutritional consideration (Acharya et al., 2014). Science-based metrics is compulsory and vital in both evaluation and enhancement of SNS (Fanzo et al., 2012; Drewnowski and Fulgoni, 2014), and is useful in categorization and comparison of different models. In addition, it can also evaluate the effect of food security and nutrition interventions in place (Gustafson et al., 2016).

The rationale behind this metric is to align the possibility of food systems contributing to health. Practices exceeding food production and food supply is the most effective way of facilitating a SNS (Ingram, 2011). However, this strategy will most likely depend on proper food transportation and storage facilities (Gustafson et al., 2016).

7.3.2.2 *The measure of diet quality*

Diet quality is defined on the platform of food diversity consumption. The basis for which one is advised to consume a balanced diet with both macronutrients and micronutrients is formulated on the assessment of diet quality. Tools to measure this aspect have for long time been the 24-hour diet recall and HDDS. Though efficient, still they have not been able to accurately determine a direct contribution on how they stimulate a change on nutrition status.

The contributions have been lingered on an assumption that by taking a range of foods, nutrition status have been made better. The metrics here need a definitive and down to the ground measurement on what quality extent does a diet contribute to adjust an individual nutrition status and by what significance of amount of calories. For example, in a 200 kcal diet of 100 kcal carbs, 25 kcal protein, and 75 kcal fats, what conversion of carbohydrate, protein, and fat have directly been transformed onto changing the nutrition status.

This kind of measurement has been tough for quite a long time but current parameters have finally dedicated time and resources to determine best metric that can quantify this metric. To realize an achievement, different approaches have to be taken that collaborates the available metrics of diet quality to newly identified metrics vis-à-vis agricultural, nutrition, and processed foods themes.

7.3.2.3 *The measure of people's ability to food accessibility*

It is difficult to measure the ability of people to access adequate, safe, and nutritious foods. While committing to this measurement, a probability is bound to be put in place to determine how easy or hard getting accessed to food is to the households across regions and the nation. Determining this will require time assessment, quantity assessment, validity assessment, food distributors and suppliers' assessment, and assessment of the number of people accessing the same food.

Factually, there has been a lot of ignorance while tackling this element; wherefore most of researchers have not approached this with an all-inclusive level metric. The basis of an all-inclusive level metric is to make sure that the evaluation is balanced and set on accuracy. For an instance, the tool for survey ought to provoke a remembrance on the respondents upon which one is easily ready to remember that he had answered wrongly in one earlier question and therefore able to rectify. This balancing creates a sensitive tool that offers a high validity and responsiveness.

Food accessibility is not limited to buying and selling of food but there are factors that facilitate these processes such as income sources, climate, hospitability and security of the area, distance where to buy or sell food, and political setups among others. Metrics assessing food accessibility should cover quite a number of these factors by over three quarter inclusiveness. This provides the basis for a clear definition of how this food is obtained and made ready for consumption.

The matter of nutritious extent of food accessed is still underlined on what income sources and amount of money one has to secure variability of foods. In brief, there are dozens of approaches to apply to this metrics to make it an efficient tool, and these may be assessed in respect to the nature of the environment and culture of the pinned-down target group.

7.3.2.4 *Improving the food intake data in quality and quantity*

Food security measurements in detail should take care of a progressive quality and quantity of data of food intake. Most research have failed to meet the standards of an efficient metric because their measurements are well as low as defined by less quality and substantial data. The parameters used might have been less balanced, less definitive, and less comprehensive to combine the components of food security to the latter determination.

Still, there is a room of expanding food security status research on a comprehensive tool that implores a wide range of data on food intake. For this to happen, there are vast indicators and subindicators at household and individual level, which may as well unveil the true picture of what need to be assessed.

For example, in a household practice farming, some of the food produced are sold and majority are consumed at home. This family has a woman as its household, and the main income is from farm. They however buy food concurrently to what they farm, but at times fall short of required sufficiency. They cannot as well remember some of the food they had taken at given times. Their lives revolve around "will I find food today?"

In this case, most researchers tend to gather data on a general circumspection rather than narrowing down into the simplest element that defines food security. This kind of entry requires a little engagement of the households being targeted (e.g., the clustered rural households). After sometime time of enlightening them, data can be collected progressively over a season of time to best compile richer information. Besides this, being a part of the household is necessary and this may be effectively applied by recruiting some of the household members, training them, and using them to gather rich household data.

7.3.2.5 *The measure of women's role in nutrition*

Most studies assume women's role in nutrition a great deal yet it is the collective point of assessing the general eating habits of the family. A study by Ogot et al. (2017) had established a positive progress in women's empowerment by assessment of roles in farming and household management from the past years. Owing to gender equality and food security measures, a simultaneous and integrated pursuit of women's contribution as regard to informing and transforming the societal nutritional status is essential. These largely complement each other and maximize their synergies to something realistic, and is yet to be done.

The focal point of nutrition starts with the mother at the breastfeeding point for a child nutritional status. The choice of foods eaten in the households is as well planned for and decided majorly by women. They are a whole menu of the food offers at home, and they have all power to set right choices or wrong choices. And because they greatly take consideration of what the children mostly need or what the entire family may need to take on a particular day, they are always the best sources to inform on household eating habits and practices.

An effective instrument for data collection will coalesce the assessment of women's role in nutrition as a validity and reliability measure, and due to the customary functions and roles women have at home, they have become the most targets of many studies. Here, metrics will form a compound view through which dietary practices at different homes are analyzed and made ready for justification according to findings.

7.3.2.6 The measure of food environment

The world faces an all-the-time increasing challenge to meet the dire demand for food produce and nutritional fulfilment against the parallel forces of increasing population amid scarce resources, drastic climate changes, and engrossed ecosystem degradation (Mathijs, 2012). Climate change element and its influence on food supply sustainability is one of the approaches employed while assessing and evaluating the pillars of the food security.

Although considerations of sustainability have always now and then been omitted from several food security assessments, this has met a hiked demand for nutritious food amid the scarce resources, leading to tremendous implications in economy, environmental, and social setups (Gustafson et al., 2016). So, to commit to establishing knowledge on sustainability and a more nutritive food supply, comprehensive metrics and tools that allow for a better understanding of the impact of environmental food systems (water, land, air, and biological ecosystems) need also to be defined (Fanzo et al., 2012; Ingram, 2011).

Food system is not deemed sustainable except that its resources base are substantive (proven by metrics) with neutral or positive outcomes on important services of the ecosystem exclusive of those of food systems (Ingram, 2011). Many studies have preferred characterizing these overall impacts with the Ecosystem Stability Metric tool. This tool has indicators that quantify the current status of ecosystems, and the indicators are clustered together with a group of eco-efficiency indicators. It reflects higher scores for food systems that have lower per-capita environmental impacts (Gustafson et al., 2016).

7.3.3 Integrating the food security metrics

Food security assessment is a chain of methodologies that investigates households' food consumption habits from the farm or agricultural source to the table. Thus food security status is efficiently determined from agriculture as a starter unit of food systems, and to utilization—an indication of individual nutritional status. A complete metric assessing food security will integrate themes around agriculture and nutrition. This surrounds all concepts ranging from household food production all way to diversification of foods consumed by each member of the household.

Currently, agriculture and nutrition are main themes that define sustainability of a widespread population. Population endeavors to fulfil sustainability in several ways that include agriculture cum income generating methods availing variety of foods to ensure nutrition sufficiency. This way, agricultural interventions have been given focus and modified, and metrics connecting agriculture and nutrition

FIGURE 7.2 Assessing the program for integrating agriculture and food security.

have been improved now and again to standardize food security pathways (Fig. 7.2).

Agricultural interventions have been consolidated and integrated into health and nutrition programs. The main focus for this development is to improve population health and nutrition at national, household, and individual levels. Active phases in defining and modeling metrics aligning to food security have yielded quite a number of achievements and failures. As a result, numerous researchers have spotted a greater need for evidences and guidance on potential relationships and synergies across these themes, and especially in terms of the mix of actions that can optimize outcomes under a single indicator in the broad metric elements of agriculture and nutrition themes.

However, the research methods that have been applied for agriculture have been very different from the ones applied in hospitals for human health and nutrition (Global Panel). In addition, the geographical scale and socioeconomic characteristic of multisectoral interventions demand an integration in these measurements. A tendency to make sure and standardize the measurement is prioritized for a change, and away from the monotonous probability of tools and methods that have been used without precision.

7.4 Measuring food security status

7.4.1 Establishing the concept and process of food security measurement

The common indicators of food security in metrics overlap between measures of accessing and of consumption. On consumption, its proper measure requires data on household food consumption (primarily), age, sex, and household size. Other less vital data required are such as activity levels of each household member and the average size of the household. But if average size and activity levels are left out, the measurement of food consumption will feature physiological sufficiency aspect of food security status. When relying on cross-sectional data, problems arise in representativeness of the consumption measurements. Therefore a suggested optimal measurements of food security should be of household food adequacy and/or caloric intake taken over time.

The advancement of food security measurements has taken a new form that surpasses food availability assessments only. Today, much emphasis has been put on the ability of a household to access food economically or their food affordability status. Therefore identifying and assembling of measurement constructs to be used will be a prioritized step when deciding on the tool of measurement. For instance, food access has many constructs with it that may need the prioritization onset. These programs may generally be affected by policies and programs at individual or collective levels, or maybe not at all.

Deciding an appropriate methodology to use greatly relies on conceptualizing the specific construct to be measured vis-à-vis intended use of the raw data to be collected (Jones et al., 2013). The types of data used, assumptions involved when measuring food security, and the intended uses of the different measurements advocate for precision, accuracy, results interpretation, and implementation of policies.

Some general questions might essentially be involved in guiding the food security metrics, and are appropriate to gather quantity and quality data. These questions include: (1) How important is the data to be collected and to whom is it useful? (2) What components of food security may be required for measurement (availability, accessibility, utilization, and/or stability)? (3) What is the general and specific purpose of the data; for example, is it for monitoring or evaluating policies, monitoring over time the food security status of target population groups, early warning of encroaching famine, monitoring utilization of programs, for purposes of inviting food aids, examining households at risk for intervention, or for advocacy purposes? (4) At what stage of causal pathways is the assessment grouped? (5) What level of food security measurement is the tool exploring (whether individual, household, regional, national, or international)? (6) What resources are available for research planning, collection and analysis of data, and implementation or application of the results obtained? (7) What periodicity is meant to be assessed, is it acute or chronic food insecurity?

In Fig. 7.3, the levels of food security is highlighted vis-à-vis the indicators of precise measurement. The critical and systematic program for needs assessment develop food security program majorly, and so is the assessment of intended use of data. The phonological setup framed by these assessments is vital to organize the food security aspects and to define the objective roles. Converged evidence-based methods make it

Levels of food security (metrics and indicators segregation)

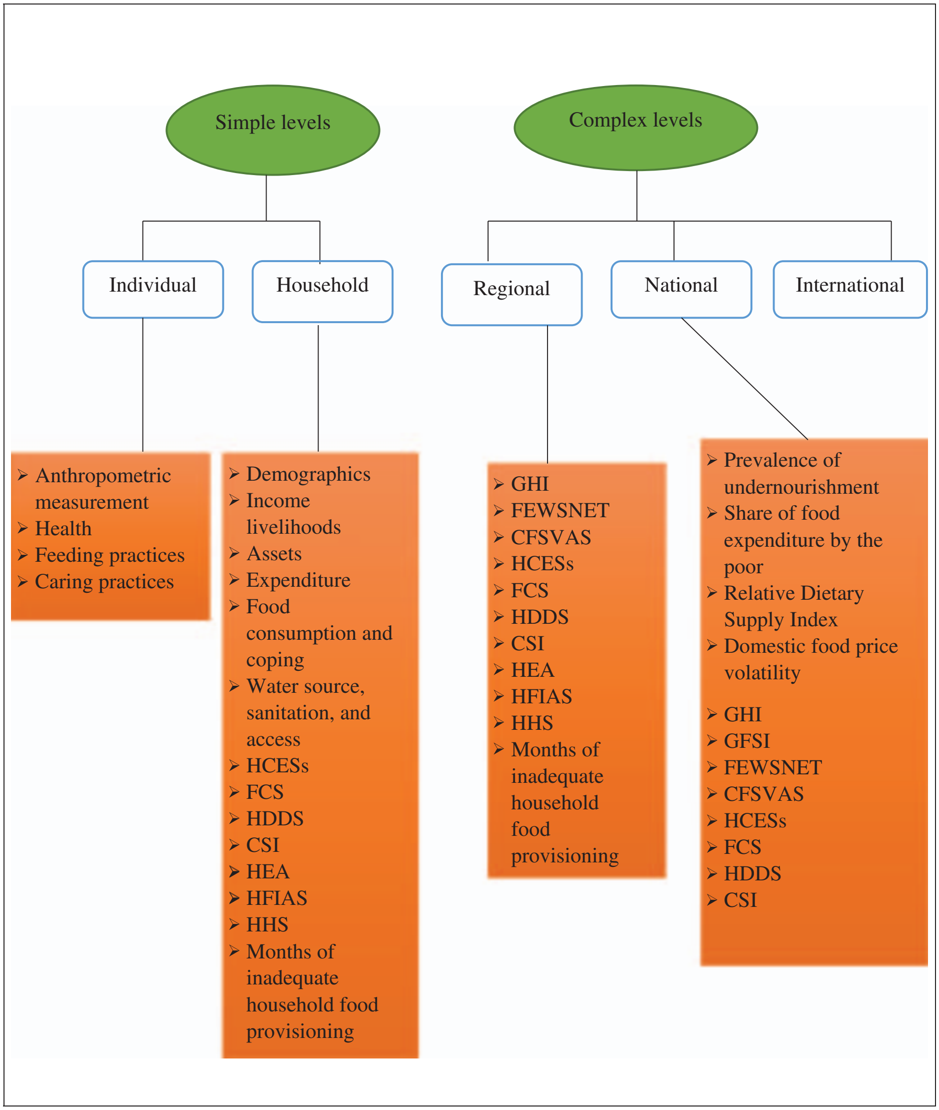

FIGURE 7.3 The assessment levels and indicators involved.

appropriate in certain special circumstances to concurrently inform on all the pillars of food security by a conceptual orientation wise. However, these planar follows at least in the bigger context of program evaluation, which is a very rare program outfit. To better identify appropriate, effective, and efficient food security, metrics may therefore require a well-suited program with sensitivity to the needs of the study and/or target purpose, and resource management—that avoids extravagance.

Identifying appropriate cutoffs for use in a setting and further making their comparisons across different regions have been the main challenges of measuring food security status. Many food security measures have formed instructions and guidelines on cutoff values, which describe and define the various levels of food insecurity. Furthermore, it is mandatory to use distributive and specific scores cutoffs, such as quartiles, in togetherness with other available proxy measurements of food security.

The food security measurements should not be homogenized in order to achieve a diversity function. This is to say, the diversity of disciplines or sectors found in food security remain relevant through program development approaches, evaluations, and formulation of policies that will achieve equality of diversity. The metric process therefore ought to be properly selected and applied in not only a thoughtful strategy but also in a systematic way in order to strengthen the relevance of all evidence-based parameters.

7.4.2 Metrics of food security by its domains

According to Section 7.4, the four domains of food security status are described in the metric-based approach to understand a broad array of indicators at each level of a unit metric. Because food security is defined at the individual level, it is therefore basic to bring in picture a combination of individual, household, community, national, and international factors. Also in describing specific metric, there is a need to conceptualize domains in their order of fulfilment. This provides for an organized module that lay a platform to array objectives and justifications of the study, and monitoring and evaluation of each of these elements for verifiability of the metric tool. These domains are, and not limited to,

1. food availability
2. food accessibility
3. food utilization/nutrition-based unit
4. food stability over time

7.4.2.1 Food availability measurement

Food availability in the simplest term is the situation where food is made to exist for consumption at local levels where local individuals or households can locate their needed foods without striving. It depicts the production and supply of varieties of foods. More so, there is a consideration of food availability process that primarily pictures consumer food choices. These considerable factors are cost, taste, cultural norms, and convenience. Apart from these, there are also factors such as socioeconomic status and ease of food accessibility, which basically affects the nutrient quality and types of food purchases (Gustafson et al., 2016). The choices made by consumers are directly linked to the sustainability and nutrition outcomes, which of these are also influenced by income disposed and amount and varieties of food available. In "Farmers Food: How push-pull technology translates the household income sources to food provision and diet adequacy" by Ogot et al. (2018a), they make emphasis on income translation to food as follows:

> Income sources are the major strength of other food purchases and diet quality of the households. A household with a higher income has the ability to value diverse foods. Income forms a more ubiquitous asset to determine a universally germane of a wide array of important policy issues. It is the sum of all the wages, salaries, profits, interests' payments, rents, and other forms of earnings received in a given period of time.

In this evaluation of a piece of work, they developed an income source model that covers: (1) the source of income, (2) the extent to which the source of income is provided in percentage, and (3) the amount of income spent on food per day. The following is the assessment model used by Nicholas Ogot et al. (2018b) to describe income sources and food availability metrics:

Assessment on food expenditure

Where does the money used for food expenditure come from?

1. Sales of farm products Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** < Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** > Kshs. 500

2. Remittances from the government/relatives/friends Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

3. Pension Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20%–50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

4. Paid salaries/wages Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

5. Rent Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

6. Dividends Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

7. Business Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

8. Others (Specify; ____________________) Yes [ ] No [ ]
- **a.** If yes, to what extent?
  - **i.** <20%
  - **ii.** 20% to 50%
  - **iii.** >50%
- **b.** What amount does it contribute per day?
  - **i.** <Kshs. 100
  - **ii.** Kshs. 100 to 500
  - **iii.** >Kshs. 500

In this unit measurement, four indicators are covered namely, food affordability, food availability, income equality, and Poverty Index. The Global Food Security Index (GFSI) has in-depth reported on food availability, food affordability, and Poverty Index in the form of spreadsheets that provide country-level scores (i.e., 0−100) for 109 countries between the years 2012 and 2015 (Global Food Security Index, 2015).

7.4.2.2 *Food affordability*

The previous assessment model (Ogot et al., 2018a) reflects a proportion of average of income that is spent on food. Economists have commonly adopted this measure of food affordability to picture out the household food availability and accessibility (World Bank 2012). Drewnowski (2010) establishes that as incomes increase, the disposable amount of income that is used on food tends to decline. In fact, he involves another set of indicators including calories and/or nutrients per unit cost. Gustafson et al. (2016) claims that it is possible to develop more complicated metrics on affordability by including price spikes and volatility, in addition, that can implore the subjective assessment responding to the environmental shocks (Global Food Security Index, 2015). Therefore they chose to define these indicators of the complicated affordability metrics as the share of household expenditures on nonfood items. This notion gets backed up in a study by Rosegrant (2012), which explains that an advantage of this definition is that it may be computed for future climate and socioeconomic cases by employing an integrated model, for example, Indigenous Movement for Peace Advancement and Conflict Transformation.

7.4.2.3 *Food availability by Global Food Security Index*

An acceptable description of having assurance of food availability is when individuals or households secure sufficient quantities of culturally appropriate food that is available from both local and commercial production. Gagnet (2003) indicates that trade enhances food availability as it reduces variability in supply and enabling economic growth. In time it even eliminates the gaps existing between consumer and producer needs. Availability of food supply ensures a direct contribution of diverse foods to individual, community, regional, national, and international circle—in turn ensuring an enabled food security system. This is by measuring the consumption of these food ranges through computations of energy contributions per kilocalories per person per year.

Choosing the GFSI Food Availability metrics is identified as much effective for a number of reasons. First, it measures factors influencing food supply and how easy it is to physically access food (Global Food Security Index, 2015). Second, it evaluates how the structural aspects attribute to the country's capacity of producing and distributing food entirely. Third, it explores the aspects that present challenges to sufficient or abundant food availability (Gustafson et al., 2016).

Here, in summary, with less legal restrictions by the structural organizations of the country to the availability of food and literally a more advanced agricultural markets, likely, food security is better placed to thrive to greater scales. And therefore with these kinds of environments, less risks are involved while featuring food supply, and market shocks can easily be tackled without zero-flatting the economic scale. Generally, there is a set measure of food availability that has been put in place by the GFSI with a major aim of determining ease of food access in each country (Global Food Security Index, 2015). The GFSI calculates these set of measurements through the Economist Intelligence Unit using various data sources such as OECD, World Food Programme (WFP), FAO, and World Bank. Further, the GFSI has availed a food availability score scaled from 0 to 100 that is used as a direct indicator.

7.4.2.4 *Income equality*

Income equality is a parameter of purchase power, wealth difference, and categorization of food security levels. Many studies have confirmed that income inequality greatly affects the food security status from the unit metric of food availability. From recent research, it is noted that sufficient production and availability of food to poorest populations are hardly possible on high levels of income inequality (Karmakar and Sarkar, 2014). This case will apply the metric of Gini coefficient (G) to measure income inequality. It provides a score of perfect income equality and unity (scaled on 0 point) and of individual's total income earnings in the country (scaled on 1 or 100). This indicator is modeled to a desired format that makes it possible to have higher values (for higher income equality) (Gustafson et al., 2016).

7.4.2.5 *Poverty Index*

Poverty is the main reason to why some households or individuals cannot afford available foods from the selling or buying sources. Not at any time can any nation achieve income sufficiency for all people in the country, and so many are bound to suffer the poverty bites. For an instance, GFSI establishes that an impoverished family may lack resources (both monetary and physical) to purchase variety of food they need. Therefore alleviating poverty has remained a primary focus toward ensuring that the food availed is accessed and consumed. In respect to GFSI poverty index is aligned on definitions and scaling by World Bank which sets a "poverty line" by the economic type of a country. The tabulated data by World Bank indicates that the population thriving under poverty are set below a "poverty line," which are either \$1.90 per day or 3.10 per day. This standard set mark has been availed universally to determine and describe populations and food system pathways. So, food availability metric does not omit the poverty situation of a locality or region.

7.4.2.6 *Food accessibility measurement*

Food access is domain of food security referring to process of accessing food physically and economically. The food access measure should assess the individuals' ability to obtain food from the supplies and how the poor people increase their accessibility to productive resources, which is a reliable guarantee of food security. The two distinct types of food access are direct or physical access, where food is produced at home by the members of the household and resources available and economic access, where food is purchased from outside the household (FAO, 1997). The physical access process might be through agriculture practice at domestic level and commercial level. The agricultural practice can also be of either diversification or monocropping, which is a component of consumption diversity assessment.

While, the economic access is the income usage to avail food, household's annual gross income is a one way method to assess the food purchasing habits by the households. Farmers have a survival tendency of keeping their households in a self-sufficient state all the time (Ogot et al., 2018b). Some even adopt a wide-ranged practice of obtaining income to thrive in a year-round food provision for their households. Ogot et al. (2018b) noted that there are several important characteristics that emanates from income sources in relation to dietary adequacy. It was observed therefore that sales of farm products among the farmers' households was the major source of income for the tested group of farmers known as push–pull farmers. On the other side, Ogot et al. (2018b) informs that other sources of income, such as paid salaries, supplemented sales of farm products, and basically for food provisions. This conformed to Ogot et al. (2017) study where the sales of farm products were found the best source of income for farming households. This entire set of income assessment proved that economic access of food access domain is as well characterized by agricultural pathways that follow subsistence production and/or income sourced components.

Most tools used to measure food access overlap on aspects of food acquisition and food consumption. In the study of "Attributes of push-pull technology in enhancing food and nutrition security" by Ogot et al. (2018b), they established that the quantity of production (a mirror form of acquisition) is highly proportional to the income level of the household just as it is with consumption, and, if production was higher as was the case of PPT, consumption and sales was found to be higher. This indicate that acquisition and consumption of food are interdependent by-products of agriculture, and are a form of immediate food access. Therefore for definite measurement, a distinction is always made between physical and economic food access aspects for purposes of clarity and effectiveness of the tool (Jones et al., 2013).

In this domain, there is apparent challenge that reduces the measurement efficiency that although many tools designed for measuring food access does assess mostly available national food supplies, they have failed to picture out household-level food patterns, behaviors, and determinants of food access. Their primary aim that puts out unit precision is that they focus much on regional- and national-level probabilistic figures and patterns.

The household-level food security measurement revolves around household food security dynamicity, and from one household to another. An improved measure of food access is better taken at household level where data from the household surveys are computed on a single unit of the national data. Therefore household food access measure is more efficient than the national measure, which commits to national data derivation.

7.4.2.7 *Food utilization measurement*

Food utilization is the third domain of food security that depicts allocation of food within households. These food allocations include quantity (amount) and quality (by variety and nature) of foods consumed by each individual member of the household (Jones et al., 2013). It also involves the nutritional quality of the accessed food vis-à-vis bioavailability of nutrients. According to FAO, food utilization is the efficient absorption and assimilation of food in the body, for which the food must be sufficient in energy and essential nutrients, and should be accompanied by adequate sanitation and potable water. Likewise, United States Agency for International Development (USAID) defines food utilization as a process of food being used effectively, food processed and stored appropriately, nutrition knowledge and child care techniques get applied, and proper health and sanitation services exist (USAID, 1992).

Food utilization is often used in deeper understanding to mean nutrition. As food utilization lingers on nutrition, it has also related to features such as health and sanitation, food processing and storage—just as they bring out nutritional aspects. The variety of food in the diet influences food utilization in the body. FSAU (2005) records that due to internutrient interaction in a food utilization function, some foods enhance the absorption of others such as fruits and vegetables, and oil enhances the absorption of some proteins and cereals. Likewise, they state that foods can also interact negatively, for example, tea can inhibit the absorption of iron, as sugar can upset the ratio of calcium to phosphorus balance, and therefore leading to increased calcium reabsorption from the bone tissue. This results to depleted bone density.

This submetric is based on assessing household's knowledge on methods of processing and storage, basic nutritional principles, and the child care process. The major reason why food utilization measure is vital is because it vivifies the understanding of household food provision. Metrics on food utilization is quite useful in apprehending how food get distributed among the households. According to Mohammadi et al. (2012) irrespective of households' adequate food supplies and their allocation to individual members of the household, unequal allocation, and nutritional deficiencies might still be apparent.

Scientists have determined that the effective use of food in the human body wholly depends on consumption of sufficient calories and variety of diets essential to provide required micronutrients (Cunningham, 2005). Controversially, because people will always strive for a full stomach, diets may be inadequate because they might have achieved quantity but not quality of diet. Also, they might select from a cheap range, which likely are of poorest quality. This means that some of the body required micronutrients might go unmet and microdeficiencies might result among the few members of the household. For instance, Bruinsma (2003) establishes that universally, significant progress has been made on consumption of food variety per individual. In precision, it has been noted that individuals have made a shift from the staple foods that was earlier main meal, and have eventually advanced to consumption of vegetable oils and the meaty products from the livestock (Bruinsma, 2003).

Therefore most studies have suggested anthropometry as the definite measure of food utilization. Anthropometry uses the measurements of human body to obtain a nutritional status information. It has long been identified as the most accurate measure of food utilization. Pelletier et al. (1995), Martorell and Haschke (2001), and Jones et al. (2013) have established that anthropometric measurements, involving body dimension measurements, are the commonest and gold standard measure of nutritional status because of their strong links to mortality outcomes, morbidity, both acute and chronic diseases, and cognitive development.

Generally the measure of anthropometry is a definite and proximal indicator of well-being in health and economic aspects (Cogill, 2003). Heymsfield et al. (2005) connotes that even though there are several advanced methods of measuring the body composition, the most applicable ones for any health and nutrition survey are recumbent length (for <3 years), height, weight, mid-upper arm circumference, and skinfolds measurements. These measurements are of simple procedures that may not need a lot of time while collecting data in the field, and are computed with each person's age and sex, and comparison is made in reference to the anthropometric index standards that depicts either acute or chronic malnutrition and/or undernourishment (WHO, 2006).

At the final findings of anthropometrical measurements, the information obtained will determine the countries with high prevalence of undernourishment, and that indicates a low life expectancy (Bruinsma, 2003). Also other factors accompanying malnutrition such as high incidence of under 5 years wasting, stunting, and mortality depict an unstable and poor food security status. These go hand in hand with the state of disease prevalence and/or child and adult health care situation.

7.4.2.8 Food stability measurement

Food stability is a measure of how long food availability, accessibility, and utilization take: the concept in food security definition of "with time." Without a prolonged security of the first three domains of food security, stability is unachievable. Therefore food stability is a test of food accessibility and consumption habits to impact on nutritional changes. Table 7.2 shows an example of a tool used to quantitatively measure household food stability (within 6 months) and their energy impacts by Ogot et al. (2017).

TABLE 7.2 An assessment tool for household food security.

Food product	Food frequency in-households (for past 6 months)		
	Frequency (1,2,3,4,5,6, or 7)	Amount consumed per day (1,2,3, or 4)	Kcals consumed per day (calculated)
Maize/wheat and their products			
Sorghum/millet and their products			
Milk and milk products			
Vegetables			
Meat/chicken and their products			
Fruits			
Pulses/legume foods			

Notes: Frequency: (1) Never, (2) once in a month, (3) 2–3 times per month, (4) 1–2 times per week, (5) 3–4 times per week, (6) 5–6 times per week, (7) over 6 times per week.
Amount consumed per day: (1) less than 100 mL, (2) 100–200 mL, (3) 200–300 mL, (4) Over 300 mL.

TABLE 7.3 Hunger gap assessment (on month-by-month basis).

In the previous years, which months have you experienced inadequate food in your household due to poor harvest?	Months												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Year _________													

Basically, food stability is influenced by environmental food systems, which includes both food supply and access aspects. Many regions experience acute fluctuations of seasonal production and access. FSAU (2005) shows Somalia as one of the regions that are affected by these seasonal fluctuations. Further, there are numerous cases of recurrent droughts (at unit regions) that affect employment opportunities, especially for those in agricultural sector, and the unpredictable weather changes. In turn, income opportunities are severely affected and so is food acquisition and consumption habits. These shocks cause steeper variations in agricultural food production, food prices, export prices of food items, movement of food commodities, and changes in production techniques (FSAU, 2005). Food intake is basically low during the hunger gap periods and malnutrition, and food insecurity normally heightens.

Another adopted model and tool assessing food stability from farm is the one inspecting the months of inadequate food across the year. This determines the monthly hunger gap and frames a Coping Strategy Index (CSI), which views across inadequacies for a solution. Table 7.3 shows a tool used for a farm household hunger gap determination across the year. It provides an ideal measure of household hunger scale (HHS) that generally determines food security status.

Based on research from the past two decades, FAO (2013) has developed this scale for global use. The following is an example of a modified frame reflecting the elements of measuring food stability:

"In the last 12 months, have you lacked money or any other resource at any time? Yes [ ] No [ ]

If yes:

1. Were you worried of running out of food?
2. Were you unable to eat nutritious food?
3. Only a few kinds of foods were accessible to you?
4. You were forced to skip a meal?
5. Did you eat lesser than the normal amount?
6. Did your household run out of food?
7. Were you hungry but cannot eat because of lacking?
8. Had you gone without eating for the whole day?"

7.5 The most modern metrics of assessing the food security status

7.5.1 Framing the modern metrics of food security: a model of identification

Owing to de Haen et al. (2011) study, food security metrics and indicators need to be purposeful for comprehensiveness of assessment. The indicators must provide answers to the expedient questions the study should have, and these are: (1) Which target group is either food secure or insecure? (2) What number are they? and (3) Where is their location? These questions express the very need for modern metrics of assessing food security status.

In this case, de Haen et al. (2011) establishes that if the purpose of measurement is beyond assessment, to include designing the policy responses, then indicators ought to answer more precise questions such as: what is the cause of people's food insecurity state? Further, what impacts do programs and policies put in place have on prevalent food insecurity? Following are the coverage of the suggested modern food security metrics in the order of unit domains of food security.

7.5.2 Types of food security measurements validated today

7.5.2.1 Prevalence of undernourishment

This tool measures food availability using a national data collected on food supply and utilization. Its basic purposes are to monitor hunger from the Millennium Development Goal, to provide comparisons from the cross-national available data, and to facilitate the food security governance both internationally and regionally. With its recall period of 1 year, it dominantly serves as an advocacy tool (Jones et al., 2013).

A study by de Haen et al. (2011) indicated that FAO indicator measures the prevalence of undernourishment. This is expressed as the percentage of people in a country that cannot meet their daily diet requirements. The FAO has approached this using a three-parameter estimates: (1) the caloric quantity average available for consumption in a country, (2) the access inequality of those calories among the people nationally, and (3) the minimum amount of calories by average required by these people (FAO, 2003).

Food availability is always emphasized when measuring country-level food security. In fact, FAO (2001) has established that tools used for measuring food availability (e.g., food balance sheets) have primarily obtained their data from food supply and utilization. Example of these raw data include total amounts of produced and imported foods (for food supply) and quantity used for food and/or nonfood uses, quantities exported, used for seed and feed for livestock, and quantity lost while storing or transporting (for food utilization). These data are important in establishing the FAO's core measurement of food security, "the prevalence of undernourishment" (Jones et al., 2013).

Based on Jones et al. (2013) science-based projection, although food supply and utilization data efficiently cover estimates of food surpluses and shortages, which project for future food demand and target setting in the agricultural sector, they are however associated with strong assumptions that the mean of the calorie consumption distribution in the population is equivalent to the average dietary energy supply according to FAO (2012) postulates. This assumption being problematic has led to unreliability of food losses information and other information on food distribution in food balance sheet. Barrett (2010) indicates that great disparities have been detected between the food-insecure households, and this is attributed to the estimated data associated with the assumption and made by the USDA.

The FAO (2012) has now published an additional set of food security indicators with their determining estimates on prevalence of undernourishment. Jones et al. (2013) record that those metrics tackle variations of the dietary energy supply vis-à-vis undernourishment measures as well as food prices information using data on country purchasing power parities and inflation rates and food deficits. The undernourishment measures here include share of energy supply obtained from plant's starchy carbohydrates (e.g., cereals, roots, and tubers), average supply of animal-origin protein, prevalence of undernourishment that considers energy needs for higher amounts of physical activity (FAO, 2012).

The 26 added indicators by FAO not only offer complementary data for defining undernourishment estimates but also assess the domains of food security past food availability. These include food access (as for tool computing the share of food expenditure of the poor) and factors determining food access such as domestic food price volatility (DFPV) and political stability.

7.5.2.2 *Domestic food price volatility*

As a component of food security status determination, DFPV is a tool of monitoring food price variability across the year. This indicator is part of the FAO suite of food security indicators in the domain of stability. It measures the index of food price level from an observed food price changes or variability of a country (scaled at national level). The indicator is calculated from the monthly consumer and general food price indices and purchasing power parity data from the International Comparison Program conducted by the World Bank. Here, growth rates are calculated monthly and standard deviation calculated over past 8 months span. These deviations are then computed to derive an annual volatility indicator.

It is useful in providing the cross-national statistics comparisons, facilitating global and regional governance of food security by standards formation, and is a national advocacy tool for food security monitoring, controlling, and coordination activities (Jones et al., 2013).

7.5.2.3 *Relative Dietary Supply Index*

Embedded in the domains of food availability and accessibility, this tool measures the country's ratio of the dietary energy supply in per capita units against the country's average dietary energy requirement, that is, average caloric needs of the population based on age, sex, and height distributions (Jones et al., 2013). This tool measures at national levels, and its sources are found in food balance sheets. It also serves as an advocacy tool for administering policy changes on food security, facilitates global and regional food security governance, and provides a crucial data for cross-national comparisons—with a recall period of 1 year.

7.5.2.4 Global Hunger Index

The Global Hunger Index (GHI) overlaps in the measurements of food physical availability, accessibility, and nutritional status. It is a tool that measures and tracks hunger globally (GHI, 2019). Scaled nationally, the index ranks countries on a 100-point scale, with 0 being the best score, meaning no hunger, and 100 being the worst. However, these extremes are never reached in practice, and the severity of hunger associated with the range of possible GHI scores is: low ≤ 9.9; moderate 10.0–19.9; serious 20.0–34.9; alarming 35.0–49.9; extremely alarming ≥ 50.0 (Von et al., 2017).

The GHI is composed of four combinations of component indicators which are: (1) the proportion of the undernourished as a percentage of the population; (2) the proportion of children under the age of 5 years suffering from wasting, a sign of acute undernutrition; (3) the proportion of the children under the age of 5 years suffering from stunting, a sign of chronic undernutrition; and the mortality rate of children under the age of 5 years (Global Hunger Index, 2016).

The data and projections used for the 2019 GHI are for the period from 2014 to 2018. The data on the proportion of undernourished come from the FAO of the UN with the estimates of the authors (FAO, 2016). While data on child wasting and stunting are collected from UNICEF, WHO, the World Bank, MEASURE DHS, and the Indian Ministry of Women and Child Development, child mortality data are obtained from the UN Interagency Group for Child Mortality Estimation (UN IGME, 2015).

With a variable recall period, its main purpose is to compare the differences in hunger across countries.

7.5.2.5 Global Food Security Index

GFSI (nationally scaled) is a tool of physical availability, economic access, food quality, quantity, and safety. It measures index of 30 indicators within the 3 domains of food security which are affordability—6 indicators measured, availability—10 indicators measured, and quality and safety—14 indicators measured. Sources for computing GFSI are both qualitative and quantitative, that is, government commitment to improving nutritional standards by presenting adequate crop storage facilities (qualitative source), food consumption in proportionality to total household expenditure, micronutrient availability (quantitative sources), and expert sources. Besides providing a cross-national comparisons of food security status, it also compares the determinants and outcomes of food security. It has a variable recall period.

7.5.2.6 Famine Early Warning Systems Network

Famine Early Warning Systems Network (FEWS NET) is a form of a monitoring tool that monitors (both nationally and regionally) a variety of information such as real-time and long-term satellite rainfall records, temperature, the NDVI, agricultural production, economic shocks, local livelihoods, trade, and prices. Sources of this measurement are derived from agriculture production reports, weather and climate records, price and trade records, economic shocks, and political stability.

FEWS NET majorly serves as an early warning system by forecasting food emergencies between 6 and 12 months advance alert (Jones et al., 2013). In addition, it assists the government and all food relief agencies to plan for food emergencies, and monitors changes over time via monthly reports on current and projected food insecurity. It has a variable recall period.

7.5.2.7 Comprehensive food security and vulnerability analysis

Comprehensive food security and vulnerability analysis (CFSVAs) is a component measure of physical availability, economic access, and food quantity. It combines analyses from secondary data with those of primary data from 13 core modules that assesses food security status and identifies underlying vulnerability causes. It measures at both national and regional levels with its sources derived from household surveys and other vital secondary data. CFSVAs are beneficial in assessment of baseline food security status of a country or region in order to advocate for an intervention planning. In addition, it examines the underlying causes of food vulnerability. The analysis may vary periodically depending on emergency situations.

7.5.2.8 Household economy approach

The household economy approach (HEA) is a component measure of physical availability and access that broadly assesses livelihood strategies, and wealth and assets. It is based on a regional and household assessment. The HEA sources vary broadly, ranging from semistructured interviews to focus group discussions among other rapid rural appraisal techniques, and also from literature review from various secondary data. It is very useful in poverty and livelihood vulnerabilities assessment and in identifying appropriate context-specific interventions. Its recall period is also variable.

7.5.2.9 Share of food expenditure by the poor

This measure is an economic access tool that measures the average share of total food expenditures by the household of lowest income quintile. The source of this tool is derived from household consumption and expenditure survey (HCES). It is also quite beneficial in providing the cross-national comparisons. It is essential in facilitating global and regional governance of food security and acts as an advocacy tool. It has a recall period of 1 year.

7.5.2.10 Food consumption score

The food consumption score (FCS) is a tool of assessing food quality and measures at national, regional, and household level. The frequency weighted diet diversity score is a score calculated using the frequency of consumption of different food groups consumed by a household during the 7 days before the survey (Vhurumuku, 2014).

The formula of FCS by Vhurumuku (2014) is as follows:

$$\text{FCS} = a_1x_1 + a_2x_2 + \ldots + a_8x_8$$

where 1…8 is the food group, a is the frequency (7-day recall), x is the weight (weight: meat, milk, and fish = 4, pulses = 3, staples = 2, vegetables and fruits = 1, sugar and oil = 0.5).

Cutoff values: poor FS = 0–21, borderline FS = 21.5–35.0, acceptable FS = $>$35.

The FCS is an appropriate indicator of measuring energy intake and diet quality from households. It offers visibility for food security status of the household together with other indicators of household access (Vhurumuku, 2014). FCS is a composite score of dietary diversity, food frequency, and nutritional importance of different food groups. The WFP mostly employs this tool for evaluating the food quality across populations. The data sources are therefore found in WFP Emergency Food Security Assessments and household surveys.

Calculating the FCS:

1. Group all the food items into specific food groups using the standard 7-day food frequency data.
2. Sum up all the food consumption frequencies from the same group, and recode the value of each group above 7 as 7.

TABLE 7.4 FCS thresholds.

Food consumption score (FCS)	FCS (high oil/sugar diet)	Profiles
0–21	<28	Poor
21.5–35	28.5–42	Borderline
>35	>42	Acceptable

Vhurumuku, E., 2014. Food security indicators. In: Integrating Nutrition and Food Security Programming for Emergency Response Workshop, Nairobi.

3. Multiply the value obtained for each food group by its weight and create new weighted food group scores.
4. Sum up the weighed food group scores. This creates the FCS.
5. Use the appropriate thresholds to recode the variable FCS, from a continuous variable to a categorical variable. See Table 7.4.

The FCS are beneficial in establishing prevalence of food insecurity, monitoring changes in food security and assisting in determination of food needs to calculate food rations. It has a recall period of 7 days.

7.5.2.11 Household consumption and expenditure survey

The HCES is an economic access, food quality, and quantity tool that collects data on all household-acquired foods, which include purchased food, foods from own production, and foods received in kind (of a limited monetary value). The HCESs is a self-source, in that it derives its general data from its own assessment and while providing complementary data to other measures. It is a purposeful tool in the measure and computation of income, food and nonfood expenditures, socioeconomic status, and consumer price indices. It is also a data source to feed food balance sheet that facilitates comparisons between different nationalities to form national policies. Its recall period may vary from 1 week, 1 month, and even to 1 year.

7.5.2.12 Coping Strategy Index

Overlapping between the domains of economic access, food quality, and food quantity, CSI is a locally adapted list of coping strategies. Its frequency usefulness is developed mainly through focus group discussions with stakeholders while severity weightings are assigned to individual strategy (Jones et al., 2013). The CSI counts the behavioral frequency and severity of people when they have less food or even money to buy food (Elliot Vhurumuku, 2014). This measurement can be done at household, regional, and national levels. The CSI derives its sources from focus group interviews and discussions. It targets food aid and keeps check on its impact, identifies vulnerable households, facilitates comparisons across contexts, and estimates changes in food security in a long-term period. It has a recall period of 30 days.

The CSI measures household and individual behavior, that is, what they do in case food gets inaccessible. Coping can be assessment of consumption changes, expenditure reduction, and income expansion. This tool always gets adopted by FAO/Food Security and Nutrition Analysis Unit (FSNAU) for Somalia, The Global Integrated Phase Classification (IPC) team, the WFP or Vulnerability Analysis Mapping unit (VAM), and so on. The rCSI measures the less-severe coping behaviors and applies five standardized-weighted strategies (Vhurumuku, 2014).

7.5.2.13 Household hunger scale

This is a measurement of economic access and food quantity domains of food security. The HHS measures the behavioral and convenience aspects of food security. It likely covers the more severe behaviors such as (1) inadequate food by availability and variability due to less or lack of resources; (2) whether any member of the household slept hungry due to less food, (3) whether any member of the household went without food for the whole of day and night due to less food.

The HHS is meant to sum up the responses obtained from three hunger-related questions. This includes a three-level frequency response questions, that is, a score from 0 to 6 is obtained and may be categorized into a three-level variable. This assessment is mainly done at household and regional levels. Main source of data for HHS is the household surveys data. The HHS is very beneficial threesome usefulness, that is, (1) it assesses hunger status within and across contexts, (2) focuses the target intervention, and (3) monitors and evaluates the impact of interventions on household hunger. It has a recall period between 1 and 30 days.

7.5.2.14 Months of inadequate household food provisioning

This tool is an economic and food quantity assessment that sums the number of months from the past year that the household had less food required by the family. It can be used to evaluate the impacts of interventions aimed at improving food access, for example, program to improve agricultural production, storage, and households purchasing power. Also, this tool measures seasonal differences and changes in the households' abilities to tackle food vulnerability. Its recall period is 1 year.

7.5.2.15 Household dietary diversity score

The HDDS is a tool of food quality assessment that sums equally weighted response data on the consumption of 12 food group and a score obtained from 0 to 12. It scaled at household, regional, and national levels (Jones et al., 2013). This type of metric captures different kinds of food groups taken by the people and their intake frequency (Vhurumuku, 2014). Sometimes this involves classifying these groups into weights. This produce a score that represents the diversity of intake, and not quantity. However these scores are significantly correlated with measures of caloric adequacy (Vhurumuku, 2014).

The primary source of data for this tool is household surveys. With a recall period of 24 hours, HDDS serves as an impact indicator of food security for USAID title II funded program. It also helps in establishing the prevalence of food security, in assessing household-level dietary diversity and in assessing changes in dietary diversity or food security over time. This dietary diversity metrics is outsourced as an objective from SDG 2, which is end hunger—achieve food security and improved nutrition, and promote sustainable agriculture.

Generally, dietary diversity signifies the varied amount of foods and/or food groups that are taken and weighed against a standard reference given (Vhurumuku, 2014). Being similar to the FCS, it is usually with a 24-hour recall period, yet without frequency information or weighted categorical cutoffs. It therefore measures household food access. Number of food groups examined range between 7 and 16. Targets of dietary diversity are varied in terms of individuals (IDDS), household (HDDS), or women (WDDS). Dietary diversity is widely promoted by the UN FAO and USAID (FANTA).

Calculation of HDDS

1. Regroup the 16 food groups in Table 7.5 into 7 food groups of HHDS. The 7 groups, designate them to be frequencies.
2. Create a new variable for each food group that provide for two possibilities below.
   1—Yes: the household/individual consumed that specific food group.
   0—No: they did not consume that food.

TABLE 7.5 Household dietary diversity score (HDDS) regrouping and calculation.

Food groups used in food consumption score	Food groups used for HDDS	Variables for 24-hour consumption of a food group 1 = yes 0 = no
Cereals and grains	1. Cereals, roots, and tubers	
Roots and tubers		
Legumes/nuts	2. Pulses and legumes	
Orange vegetables (rich in Vit A)		
Green leafy vegetables	3. Vegetables	
Other vegetables		
Orange fruits (rich in Vit A)	4. Fruits	
Other fruits		
Meat	5. Meats, fish and seafood, and eggs	
Liver, kidney, heart, and/or other organ meats		
Fish/shellfish		
Eggs		
Milk and other dairy products	6. Dairy products	
Oil/fat/butter	7. Oils and fats	
Sugar or sweets	Not considered	
Condiments or spices	Not considered	
	HDDS (score)	

Vhurumuku, E., 2014. Food security indicators. In: Integrating Nutrition and Food Security Programming for Emergency Response Workshop, Nairobi.

3. Sum up all the variables in order to find an HDDS.
4. The new variable will be of the range between 0 and 7 of the maximum food groups number.

7.5.2.16 Analyzing and classifying household dietary diversity score

The dietary diversity score can be disaggregated by sex of household head, strata and other areas of interest as in Table 7.6.

7.5.2.17 Household food insecurity access scale

The household food insecurity access scale (HFIAS) is a tool in the domain of economic access, food quality, food preferences, and anxiety. It was designed to include household behaviors that showed insufficiency in quality and quantity. It is as well an estimator of anxiety and uncertainty of insecurity to food supply. It rounds up nine food security related responses, and these include a four-level frequency response questions, then a score from

TABLE 7.6 Dietary diversity score (DDS) disaggregation by sex.

		DDS before intervention		DDS after intervention	
		Average	Median	Average	Median
Sex of the household head	Female	4.4	4.1	6.1	6.0
	Male	4.7	4.4	6.8	6.4
Total		4.5	4.2	6.5	6.2

Vhurumuku, E., 2014. Food security indicators. In: Integrating Nutrition and Food Security Programming for Emergency Response Workshop, Nairobi.

0 to 27 is obtained and categorized into a four-level variable. This tool can be assessed at both regional and household level. Its data source is also household surveys, and it is vital in assessing food security status within regions or households and monitoring and evaluation of impacts of food security interventions. Its recall period is 30 days.

7.5.2.18 Anthropometry

According to National Health and Nutrition Examination Survey (NHANES), anthropometry is the study of the measurement of the human body composition such as bone, muscle, and adipose or fat tissue. The word "anthropometry" comes from two Greek words "anthropo" meaning "human" and "metron" meaning "measure." It encompasses the measurement of various human body parts. Examples of anthropometric measures include weight, stature (standing height), recumbent length, skinfold thicknesses, circumferences (head, waist, and limb), limb lengths, and breadths (shoulder, wrist) (National Health and Nutrition Examination Survey, 2017).

The common indicator of body fat is the body mass index (BMI). BMI values are calculated for NHANES participants using measured weight and height values as weight (in kilograms)/height squared (in meters). The BMI assesses weight status in children, adolescents, and adults. As for children and adolescents, the cutoff criteria are based on the gender-specific BMI-for-age growth charts, that is, underweight (BMI values $<$ 5th percentile); healthy weight (BMI values 5th–84th percentiles); overweight (BMI values 85th–94th percentiles); and obesity (BMI values $\geq$95th percentile). For adults, cutoff criteria are fixed, that is, underweight (BMI values $<$ 18.5); normal weight (BMI values 18.5–24.9); overweight (BMI values 25.0–29.9); obese—Class I (BMI values 30.0–34.9); obese—Class II (BMI values 35.0–39.9); and extremely obese—Class III (BMI values $>$ 40.0). The NHANES BMI results are used to track weight trends in the U.S. population (National Health and Nutrition Examination Survey, 2017).

7.5.3 The meta-analysis of food security situations and nutritional statistics

The population on the receiving end of the food security and nutrition, and the natural allies in the food systems, gender, Water, Sanitation and Hygiene (WASH), agriculture, social protection and health communities, advocate for action-oriented, measurable targets for improved nutrition within the SDG framework (Webb, 2014). IFPRI (2014) details that since 2000, the nutrition situation has become more complex where quite a number of countries experience multiple deprivation of good nutrition status such as undernutrition, overweight, and micronutrient malnutrition. Simultaneously, these three conditions may occur at all levels of household and individual (Nutrition Targets and Indicators for the Post-2015 Sustainable Development Goals).

The targets of food security and nutrition interventions are worldwide. They include vulnerable groups from regions of Asia and Africa which are stunted children of under 5 years of age (56% in Asia and 38% in Africa), wasted children of under 5 years of age (are about 69%−71% in Asia and 28% in Africa), and childhood overweight (18% in Southern Africa and 12% in Central Asia), anaemia in women of reproductive age (29% of nonpregnant women and 38% of pregnant women of between 15 and 49 years of age), and low birth weight (15−20% of all births worldwide are low birth weight and representing more than 20 million births a year).

7.5.4 Rationale of nutrition progress measurement

Nutrition progress should be exhaustively screened for comprehensiveness of measurement to be obtained (Nutrition Targets and Indicators for the Post-2015 Sustainable Development Goals). Many nations with high malnutrition prevalence are committed to curbing this condition, which supposedly is limited, and that is by collection of inadequate data on nutritional elements of population. The quality and coverage of the disaggregated data must therefore be improved significantly in order to adequately support policy decisions and intervention programs. Further, scaling up the nutrition-sensitive interventions in terms of monitoring and evaluation is very essential. First, efficient and comprehensive data should rely on a high-functioning national nutrition data collection systems, which include findings from administrative sources, health facilities, and surveys among others. Second, data based on comprehensive capacities in best quality data collection, analysis, and communication form a more effective use of monitoring and evaluation for both the national and worldwide progress measurement. It can also be more effective on decision-making at subnational levels.

7.6 Summary and review

The definition of food security began from the early 1970s as a concept of “food supply” and evolved across the years to “the state when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life,” as described by FAO (1996).

Rationale behind metrics for identifying food security status is based the goal-focus of food security research, and this aligns to the SDG’s. A composite metrics might be involved here, where the study employs numerous indicators, which leads to usage of multiple algorithms. Hence, indicators are derived from multiple variables of data obtained from modeling and direct field observations.

The particular choice of metrics to be used in a study is very dependent on target group(s), environment, type of food, and farming methods among others. But modern studies tend to apply techniques in quantifying data on selected components to depict numbers instead of basing them on mere guess. The four pillars or domains of food security have in this case covered the elements for food security status metrics. These pillars are availability, accessibility, utilization, and stability. Several studies have chosen to combine these pillars together with environmental and political factors for a standard metric. However, modern food security metrics needs adjustment in the six key areas of (1) including metrics for measuring the food systems’ healthiness, (2) agreement on diet quality measurement, (3) including measurement of people’s ability to accessing adequate and good quality food, (4) improvement of the food intake data quality and quantity, (5) including measurement of women's roles in dietary choices, and (6) including the measurement of the food environment.

In measuring food security status, a must guiding questions are gauged to get quantity and quality data. The questions are: (1) How important is the data to be collected and to whom is it useful? (2) What components of food security may be required for measurement? (3) What is the general and specific purpose of the study? (4) At what stage of causal pathways is the assessment grouped? (5) What level of food security measurement is the tool exploring? (6) What are the resources available for planning, data collection, analysis, and implementation on or application of the results obtained? (7) What periodicity is meant to be assessed, is it acute or chronic food insecurity?

Briefly, the measurement of food security components provides a rationale for insights and forecasts for future development of metrics. This is based on the description of the domains of food security as follows:

1. *Food availability*: It is the analysis of a situation where food exists at local levels for consumption without striving to locate needed foods. Here, production and supply of varieties of foods are the involved indicators and determinants of measurement. This component includes four submetric indicators: food affordability, food availability by GFSI, income equality, and Poverty Index.
2. *Food accessibility*: This component measures individuals' ability to get food supplies and how the poor people increase their physical accessibility to productive resources. Two types of food access are physical access and economic access.
3. *Food utilization*: This component includes amounts and kinds of food consumed by individual household member that is able to impact to nutritional status determination. Food utilization is most often titled with nutrition, but while utilization bases its focus on nutrition, it includes food storage, processing, health, and sanitation in a tied relationship to nutrition as well.
4. *Food stability*: This component measures how long food availability, accessibility, and utilization go. It is a test of food accessibility and consumption habits that impacts to nutritional changes. This is where HHS or food adequacy/inadequacy is applied for assessment.

The current metrics for identifying food security presented here include:

- Prevalence of undernourishment
- DFPV Index
- Relative Dietary Supply Index
- GHI
- GFSI
- FEWS NET
- CFSVAs
- HEA
- Share of food expenditure by the poor
- FCS
- HCES
- CSI
- HHS
- Months of inadequate food provisioning
- HDDS
- HFIAS
- Anthropometry

These metrics complete a general need for appropriate and modern measurements of food security status identification for intervention programs, monitoring, and evaluation of progress.

Abbreviations

CFSVA Comprehensive food security and vulnerability analysis
CSI Coping Strategy Index

DFPV	Domestic food price volatility
EIU	Economist Intelligent Unit
ESM	Ecosystem Stability Metric
FAO	Food and Agriculture Organization
FCS	Food consumption score
FEWS NET	Famine Early Warning Systems Network
FSAU	Food Security Analysis Unit
GFSI	Global Food Security Index
GHI	Global Hunger Index
HCES	Household consumption and expenditure survey
HDDS	Household dietary diversity score
HEA	Household economy approach
HFIAS	Household food insecurity access scale
HHS	Household Hunger Scale
IFPRI	International Food Policy Research Institute
IMPACT	Indigenous Movement for Peace Advancement and Conflict Transformation
MUAC	Mid-upper arm circumference
OECD	Organization for Economic Co-operation and Development
RDSI	Relative Dietary Supply Index
SDG	Sustainable Development Goals
SNS	Sustainable nutrition security
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WASH	Water, Sanitation and Hygiene
WFP	World Food Programme
WHO	World Health Organization

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CHAPTER

8

Public policies, food and nutrition security, and sustainable food systems: convergences from the Food Acquisition Program

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8.1 Introduction

The creation of Food Acquisition Program (Programa de Aquisição de Alimentos [PAA]) in 2003 represented a major innovation in Brazilian public policies, articulating elements of agricultural policy with actions related to food and nutrition security and social assistance (Grisa and Porto, 2015; Delgado et al., 2005; Schmitt, 2005). Created in a context of hunger returning to the public agenda, of the strengthening of policies for family farming,[1] and of the (re)creation of institutions dedicated to food and nutrition security, PAA expresses an effort of intersectoral articulation and comanagement between state and society around food (Grisa and Schneider, 2015). Through the Program—and particularly through the Simultaneous Donation modalities—, the government purchases food from family farming and distributes it to organizations of social assistance that assist vulnerable people, connecting a wide range of organizations and social mediators. Through other modalities, the program also provides added value and price assurance for family farming, donation of seed from food crops to socially vulnerable family farmers, and purchase of food for consumption in public administration facilities (Box 8.1).

[1] According to Brazilian law, family farming are all rural estate with an area of up to four fiscal modules, which have predominantly family labor, a minimum percentage of income from the establishment activities and the family running the administration. This definition includes agrarian reform settlers, artisanal fisherfolk, extractivists, indigenous peoples, and remnant communities of rural quilombos (Brasil, Presidência da República, 2006a).

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BOX 8.1

Summary box of the implementation modalities of the PAA in 2019.

Modality	Characteristics
Simultaneous donation purchase	Buys miscellaneous food and donates to organizations of the social assistance network, to public food and nutrition devices, or to other purposes defined by the Managing Group. The modality may be performed by the National Supply Company (CONAB), by the states or by the municipalities. Farmers can participate individually or through cooperatives/ associations. Limit per family unit/year: R$ 6500. Limit per family unit linked to a supplier organization/year: R$ 8000. Limit per organization/year: R$ 2 million
Stock formation	Acts to financially support the formation of food stocks by supplying organizations, for later commercialization and return of resources to the public power. Modality performed by CONAB. Limit per family unit/ year: R$ 8000.00. Limit per organization/year: R$ 1.5 million
Direct purchase	Buys products defined by the PAA Management Group, in order to support prices. Limit per family unit/year: R$ 8000. Limit per organization/year: R$ 500,000
PAA milk	Enables the purchase of milk, which, after processing, is donated to the beneficiary consumers. It is operated by state governments in Northeast Region and Minas Gerais. Limit per family unit/year: R$ 9500
Institutional purchase	Buys from family farming, through public call, in order to meet the consumption needs of food, seeds, and other propagative material by the buyer government agency. Limit per family unit/year: R$ 20,000. Limit per family farming organization/year: R$ 6 million
Seed acquisition	Buys seeds, seedlings, and propagative materials for human or animal food from beneficiary suppliers, in order to donate to consumers or suppliers beneficiaries. Limit per family unit/year: R$ 16,000. Limit per organization/year: R$ 6 million

Source: created by the author, based on consolidated legislation (Brasil, CONAB, 2018).

Since its conception, the Program innovations and results have been the object of attention by the academy, social movements, politicians, and international organizations (Sabourin et al., 2020; Sambuiche et al., 2019; Milhorance et al., 2019; Valencia et al., 2018; Lopes Filho, 2018; Costa Leite et al., 2013). Inspired by national experience, several subnational governments have created similar actions, as the Agriculture Production Acquisition Program of the Federal

District – Papa-DF (Programa de Aquisição da Produção da Agricultura do Distrito Federal) and the Paulista Social Interest Agriculture Program – PPAIS (Programa Paulista da Agricultura de Interesse Social). And the same have happened in the international level. The Purchase from Africans for Africa – PAA Africa, implemented in five Africans countries (Ethiopia, Malawi, Mozambique, Niger and Senegal), the Lèt Agogo Project (Milk Abundance) in Haiti, and public procurement in Mercosur countries are examples of programs inspired by PAA (Lopes Filho, 2018; Grisa and Niederle, 2018; Maluf et al., 2016). In a speech in July 2012, former President Dilma Roussef stated: "If we are going to make a suggestion, show a technology to any other country, I think that technology would the PAA and PNAE [National School Feeding Program – Programa Nacional de Alimentação Escolar], which is how we are able to give sustainability to production, ensuring the purchase and ensuring that families, who invested there, will not run out of place to put their product, without buyers." (Brasil, Presidência da República, 2012). In a similar way, a paper of Food and Agriculture Organization of the United Nations (FAO) entitled "Smallholder integration in changing food markets," stated that "In many Latin American countries, governments are taking a more direct approach to integrate smallholders into domestic markets by linking the demand for food purchases in social programs to the supply of locally produced food. Brazil has been most active in implementing this type of initiative, with its PAA, created as part of the Zero Hunger Strategy, used to facilitate direct government procurement of food products from smallholders." (FAO, 2013, p. 37).

This academic, political, and institutional effervescence around the PAA instigate us to reflect on the reasons for this phenomenon. Why the PAA has been the object of so much discussion and why has it been so welcomed institutionally? What contributions does it make to food and nutrition security and the construction of sustainable food systems? And, regarding national and international repercussions, how have these contributions influenced the program's own national trajectory? Have they contributed to the strengthening of the program over its almost 20 years?

Regarding these matters, this article has two main objectives. The first is to analyze PAA's contributions to food and nutrition security and to the building of sustainable food systems in Brazil; for this discussion, we examined mainly the modalities that bring food as a central focus and that connect producers and consumers, presenting a greater interface with food and nutrition security. The second objective is to summarize the program's national trajectory, pointing out its recent phases and challenges. The focus is to analyze the possible synergies between the PAA's national and international political and institutional repercussions and its political and financial trajectory in the country.

Conceptually, according to the Organic Law on Food and Nutrition Security (Lei Orgânica de Segurança Alimentar—Law n. 11.346/2006), food and nutrition security is the "fulfillment of the right to regular and permanent access to quality food in sufficient quantity, without compromising access to other essential needs, based on health-promoting dietary practices that respect cultural diversity and are environmentally, culturally, economically and socially sustainable" (Brasil, Presidência da República, 2006b). The law also stresses that promoting food and nutrition security implies expanding the conditions of access to food by strengthening the production of family farming, the conservation of biodiversity, and the sustainable use of resources. Furthermore, it must promote the health, nutrition and food of the population; ensure the biological, health, nutritional, and technological quality of food; encourage healthy eating practices and lifestyles that respect the population's ethnic, racial, and cultural diversity; promote knowledge and information sharing, and implement public policies, and sustainable and participatory strategies for food production, commercialization, and consumption, respecting the country's diverse cultural characteristics (Brasil, Presidência da República, 2006b).

The promotion of food and nutrition security depends directly on how the food system is organized. This system is defined as the interrelated set of activities and actors involved in food production, distribution, storage, processing, preparation, and consumption; resource production (seeds, fertilizers, packaging, and so on) and waste management; and the creation and implementation of activities and of regulatory and governance institutions (Bricas, 2019; Bricas et al., 2017). According to the High-Level Panel of Experts on Food Security and Nutrition, created by the United Nations Committee on World Food Security, the sustainable food systems are those that can "ensure food and nutrition security for all in a way that the economic, social and environmental bases necessary to generate food and nutritional security for future generations are not compromised." (HLPE, 2014, p. 31). More specifically, Bricas et al. (2017) state that sustainable food systems are those that protect the environment and biodiversity without damaging nonrenewable resources and without polluting; promote access to sufficient, healthy, nutritionally and culturally accepted food; involve an inclusive economy that creates jobs, generates greater equitable distribution of added value, and lowers social inequality; strengthen social cohesion and respect for cultural diversity; and restore confidence in the system while encouraging citizens to participate in its development.

Based on these concepts, this chapter analyzes PAA contributions and trajectory. Based on the systematization of field research conducted in different contexts of the country, from 2011 to 2018, as well as research results from other studies, this chapter seeks to explore the interactions between public policy, food and nutrition security, and sustainable food systems from PAA. For this, the article is divided into five more sections. Section 8.2 presents some characteristics of the Brazilian food system, contextualizing the productive, economic, and social environment in which PAA is inserted. This contextualization is important for it offers the opportunity to better understand the results and changes brought about by the PAA, which are discussed in the following sections. Section 8.3 presents PAA building and operationalizing processes, which break the political and economic "distancing" (Bricas et al., 2017) and contribute to the construction of food democracy. Section 8.4 explores the program contribution to change the hegemonic food system and the approximation (as opposed to the distancing) between producers and consumers. Section 8.5 presents some challenges that permeate the program trajectory and execution that affect its continuity. Finally, the chapter presents some thoughts about PAA development and contribution and about the analysis developed in this work.

8.2 Characteristics of the Brazilian food system: the context where Food Acquisition Program is inserted

Several elements, political options, and development plans, along with Brazilian development trajectory, offered challenges for the building of sustainable food systems. According to Linhares (1979), unequal access to land, the subordination of agricultural production to the dominant interests of large export crop plantations, and the use of food supply to speculative purposes created food supply crisis and marked the period of colonization to the end of 19th century and beginning of 20th century. Since 1930, in the context of promoting the country's industrialization, the theme of food supply, feeding, and hunger arose and became more visible, demanding state action. Several public policies and instruments were created to stimulate agricultural production and to improve the diet of workers and socially vulnerable populations. Some of these policies and instruments had a very sectoral character, and others had a short, fragile, and unstable existence (Fogagnoli, 2011; L'Abbate, 1988; Linhares and Silva, 1979).

During the 1960s/1970s, in the context of advancing industrialization and increasing urbanization in the country, new actions and instruments were directed toward the modernization of agriculture and urban supply (Belik et al., 2001; Graziano da Silva, 1999; Linhares and Silva, 1979). New products, technologies, and inputs have boosted the production of raw materials and commodities, and again gave impulsion to agriculture-oriented toward export or industrial interest groups. This situation set up the agroindustrial complex in the 1980s, linking agriculture to input and transformation industries and to distribution and retail sectors. Small-scale agriculture—also recognized at that time as subsistence production or production of low income—was dismissed from state actions, facing difficulties in social reproduction, and reinforcing urbanization process through the intense rural exodus (Graziano da Silva, 1999). Due to urban growth, several supply structures were created in the 1970s (National System of Supply Centers—Sistema Nacional de Centrais de Abastecimento; Supply Centers—Centrais de Abastecimento; Network Somar—Rede Somar; and Program of Supply in Low-Income Urban Areas—Programa de Abastecimento em Áreas Urbanas de Baixa Renda), which were questioned in the 1980s/1990s due to the operational and financial difficulties and, mainly, to the advance and the structuring of supermarkets in the country (Menezes et al., 2015; Cunha and Belik, 2012).

During the 1980s/1990s, state actions decreased as a result of the economic crisis, the structural adjustment, the advance of neoliberal ideas, and the understanding that mercantile relations would solve food supply and food and nutritional security. Resources for social assistance organizations and agriculture policies were reduced, and policies and institutionality related to food and nutrition security were extinguished (Belik et al., 2001; Peliano, 2001). However, according to Belik et al. (2001, p. 123), "the change in focus has not slowed the growth of the agribusiness sector, especially export-oriented segments, which continued to show increasing results in terms of quantities produced."

In the 2000s in a neo-developmental context, the state resumed its role in development, there were significant productive, economic, and political advances in the agribusiness sector, and at the same time, a broad set of actions were devised to promote family farming and food and nutrition security (Vasconcelos et al., 2019; Grisa and Schneider, 2015; Delgado, 2013). According to Favareto (2017), it was a schizophrenic strategy that relied heavily on the primarization of the economy via commodity exports and, at the same time, triggered policies based on the rights of the poor and inclusive institutions to compensate for concentration and structural exclusion generated by it. Indeed, the production of commodities and the intensive agricultural model competed for space with food production and with traditional communities, threatening biodiversity, food and nutritional security, and the promotion of sustainable food systems (Favareto, 2019; Sauer, 2019, 2018; Almeida, 2012).

During this long trajectory, even if agricultural production increased and the supply crisis decreased, historical characteristics were reproduced, and new problems and food issues emerged. One of these characteristics is structural inequality in Brazil's agrarian environment. According to the 2017 Agricultural Census, establishments with up to 10 ha represent 50.13% of Brazilian rural establishments but occupy only 2.27% of the area dedicated to agriculture. In turn, establishments with more than 1000 ha represent 1% of the establishments and account for 47.6% of the agricultural area

(IBGE, 2019). Regarding family farming, such inequality is also present: it accounts for 77% of Brazilian rural establishments but occupies only 23% of the area (IBGE, 2019). It is noteworthy that public and institutional recognition of family farming by Brazilian State is recent—the first public policy specific for this social category was created in 1995 (National Program for Strengthening Family Farming—PRONAF).[2] Despite this recognition, most of the public budget directed to agriculture and rural areas continue to be directed to the agribusiness sector (Sauer et al., 2017; Niederle et al., 2019). These structural inequalities generate, on the one hand, exclusion and food and nutritional insecurity and, on the other, models of agriculture that intensify the inequalities (Haddad et al., 2016).

Another continuity concerns the priority of production for export. According to CONAB (n.d.),[3] between the 1976/1977 harvests and the forecast for the 2018/2019 harvest, there was a 516% increase in soybean acreage. This oilseed has been considered the largest cultivation of national agriculture due to its territorial importance (33.2 million hectares planted in 2015/2016, which is equivalent to 57% of temporary crops) and its economic−commercial expressiveness (14.6 % of total exports in 2015) (Wesz Jr. and Grisa, 2017). Much of the national soy production is directed to exportation (74%), with little value added (73% of export sales are fresh grain) (Wesz Jr., 2014). While production for export grew, crops mainly directed to the domestic supply and daily life of Brazilians were reduced. Between the 1976/1977 harvests and the forecast for the 2018/2019 harvest, areas for wheat, bean, and rice production had a reduction of 37%, 35%, and 71.3%, respectively. Besides this export orientation, agricultural production focuses on a few products. According to IBGE (2019), soybeans, sugar cane, corn, coffee, and cotton accounted for 73.6% of national production in 2018,[4] converging to a worldwide diagnosis[5] that points to threats to food diversity. Moreover, these products are associated with the intensive use of pesticides. According to Bombardi (2017), between 2000 and 2014, there was an increase of 135% in the consumption of pesticides; the soybean crop accounted for 52% of all sales in 2015 and, adding the uses in the production of corn and sugar cane, this percentage reached 72%. According to Pelaez et al. (2015), Brazil has become the second largest national market and the world's largest importer of pesticides since the 2000s.

Regarding livestock, it is important to highlight that the cattle herd grew 69% in the period from 1975 to 2017, and 77% of this growth occurred in the Amazon region (Ohashi et al., 2018). According to Ohashi et al. (2018), during this same period, the cattle herd in the Amazon increased from 5,119,585 to 59,682,788 animals, an increase of 1066%. Following this process, the authors record the

[2] PRONAF marked the political and institutional recognition of the Brazilian State to family farmers. Until then, they were virtually ignored by national policies and had serious difficulties in staying in the countryside. The construction of the Program involved intense demands, proposals, and mobilizations by the social and union movements of family farming in the late 1980s and especially in the early 1990s (Grisa and Schneider, 2015).

[3] Available at: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras.

[4] Available at: https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/25371-pam-2018-valor-da-producao-agricola-nacional-cresce-8-3-e-atinge-recorde-de-r-343-5-bilhoes.

[5] According to the report "The State of the World Biodiversity for Food and Agriculture"; less than 200 of the world's 6000 cultivated species contribute substantially to global food production, and nine of them account for 66% of world agricultural production (FAO, 2019).

growth in 990.5% of the deforested area for cultivated pasture formation.

> The big problem is that pasture formation was carried out by burning and without any technical agroecological criteria, aggravating the environmental damage, especially in relation to the preservation of riparian forests on river banks and preservation forests around the springs, affecting especially small streams, many of which were once perennial, but currently dry completely in the dry season, affecting the volume of the rivers into which they flow. (Ohashi et al., 2018)

These dynamics and characteristics of agriculture and livestock go against the concerns about climate change. According to Piatto et al. (2017), Brazilian agriculture accounted for 30% of net greenhouse gas emissions in 2015, and if the mensuration includes indirect emissions from the sector (deforestation of natural ecosystems for agricultural expansion, use of fossil fuels in agriculture and emissions resulting from industrial effluent treatment), this percentage reaches almost 70%. According to the authors, direct emissions from the agricultural sector have grown by 165% since 1970, and the main responsible were enteral fermentation of the ruminant herd (mainly beef cattle) and activities on agricultural soils (including synthetic fertilizers, animal manure, animal waste deposited on pasture, and agricultural crop residues).

Thus organized, the agricultural model adopted in Brazil allowed increasing (in an unsustainable way) food production, productivity, and availability. Indeed, according to Rapallo and Rivera (2019), the average availability of food energy in Brazil in the 2015–2017 period exceeded by 21% the minimum recommended requirements for an active and healthy life. However, this model failed to solve "old" problems such as hunger. Even though hunger was reduced in the 2000s, FAO data (FAO/OPS/WFP/UNICEF, 2018) showed the existence of 5.2 million Brazilians with malnutrition in 2017. Data from the National Household Sample Survey (IBGE, 2013) indicated that in 2013, 22.6% of the households (14.7 million people) had some degree of food insecurity: 14.8% presented marginal food insecurity, which means to say that they were concerned about access to food in the future; 4.6% had moderate food insecurity, which means some limitation of quantitative access to food; and 3.2% had severe food insecurity, manifested in the experience of hunger for at least one individual of household. Far from arising from food supply crises, such phenomena are related to the difficulties of access to food, especially the quality and healthy foods. Therefore there are reservations and questions about the speeches that claim the increase of production, the productivist and productionist bias in public policies, and the maintenance of the food system as it stands (Rapallo and Rivera, 2019; Fouilleux et al., 2017).

At the same time, that hunger was not extinct, new food problems arose, such as for overweight and obesity, which are linked to noncommunicable diseases, for instance, diabetes, high blood pressure, heart attacks, and some types of cancer. According to the Ministry of Health (Brasil, MS, 2019a), in 2018 over half of the population of Brazilian capitals (55,7%) were overweight and one in five Brazilians (19.8%) were obese. A campaign by the same Ministry states that 3 out of 10 children aged 5–9 years are overweight (16% of them are overweight, 8% are obese, and 5% are severely obese), 15.9% of children under 5 years are overweight, and the consumption of ultra-processed foods is becoming increasingly precocious (Brasil, MS, 2019b).

These new food problems are associated with the hegemonic agricultural model and the dynamics of food transformation, distribution, and consumption. In terms of consumption, we highlight the diet based on ultra-processed products, in detriment of fresh, semiprocessed, and processed foods (Pan American Health Organization, 2018).

As established by the NOVA food classification system, ultra-processed products, despite being tasty (sometimes addictive), have "poor nutritional quality" mimic healthy foods; instigate snacks consumption; are culturally, socially, economically and environmentally "destructive"; and are associated with overweight and obesity (Pan American Health Organization, 2018, p. 06).

Data from the Pan American Health Organization (2018) show that Brazil is in 34th position among the 80 countries (with available data) on per capita retail sales of ultra-processed products. According to the report, between 2000 and 2013, there was a 30.6% increase in sales of ultra-processed food and drink products in Brazil, an average annual growth of 2.1%. In the same period, purchase of fast food per capita was increased by 25%, and in 2013 Brazilians and Peruvians "were by far the largest consumers of fast food in Latin America, with consumption 10 times higher than in Bolivia" (Pan American Health Organization (2018, p. 23). According to a representative survey across the country, Opinion Box Insights (2019) found that 44% of respondents go to fast-food chains at least once every 15 days or more often, 67% usually buy products from fast-food chains, and 44% usually order to deliver at home. In turn, between 1987/1988 and 2008/2009, the low consumption of fruits and vegetables remained stable, and in 2008 these products represented only 2.9% of the total consumed calories (2.2% for fruits and 7% for vegetables) (Canella et al., 2018). Moreover, according to Canella et al. (2018, p. 5), "There is an inverse relationship between the purchase of vegetables and ultra-processed foods, in other words, households with a higher caloric share of ultra-processed foods in the diet purchased fewer vegetables."

According to the Pan American Health Organization (2018, p. 5), "Most products that are sold in supermarkets, especially in the central aisles and at the beginning of the aisles, are ultra-processed, and the same is true for most convenience stores and fast food places." As a matter of fact, Machado (2016) demonstrates that supermarkets were the main place to buy food in Brazil in 2008/2009, contributing with more than half of calories purchased (59%), followed by small markets (15%), street and public markets (8%), and bakeries (8%). According to the study, 60.4% of calories from ultra-processed products available for consumption in households were purchased from supermarkets, and over 75% of calories from bars/cafes/restaurants were from ultra-processed foods. In addition, the author noted that the increased participation of supermarkets in access to food tended to increase the participation of the ultra-processed in the diet (Machado, 2016). In turn, two-thirds of all calories purchased at the street and public markets, butchers, small producers, and street vendors came from fresh or minimally processed foods (Machado, 2016).

Besides the association with overweight and obesity, in general, ultra-processed foods and their production and distribution dynamics involve long supply chains, distances between producers and consumers, and by dynamics that concentrate wealth and produce inequalities. According to Pan American Health Organization (2018), the four largest companies in carbonated drinks and sugary and salted snacks account, respectively, for 84.6% and 81.9% of total sales of the sectors in Brazil. In his analysis, ultra-processed products are increasingly being marketed in large retail food outlets, such as hypermarkets and supermarkets, as well as convenience stores. In his words, "the markets for various ultra-processed products are oligopolistic and dominated by transnational corporations" (Pan American Health Organization, 2018, p. 32). Corroborating these data, the Brazilian Association of Supermarkets (Associação Brasileira de Supermercados) points out that, among the 500 largest companies in the sector that operated in the country in 2018, five of them accounted for 46.9% of total revenues (ABRAS, 2019).

Such characteristics, however, are not specific to the distribution sector. In analyzing the tractor, harvester, fertilizer, pesticide, seed, processing, and distribution industries operating in Brazil, Niederle and Wesz Jr. (2018, p. 108) state that "in recent years there has been an expansion of concentration and transnationalization in the different segments of the agri-food system, amid innumerable initiatives of merger, purchase, and partnership between large companies operating globally." As mentioned by Ploeg (2013, 2008), the production, processing and marketing of foods have become controlled by a few large companies that operate on a world scale, forming food empires. They are "agribusiness groups, large retailers, state mechanisms, but also laws, scientific models, technologies, etc.," that, in both time and space, disconnect food production and consumption, distancing agricultural production from local ecosystems and societies, distancing producers and consumers from decision-making, concentrating and centralizing power, and producing inequality and social exclusion (Ploeg, 2013, p. 20).

These characteristics of the food system worsen in a context of increasing urbanization. Although Brazil has a large territorial area and rural elements are significant in the country's dynamics, 84.4% of the population lives in urban areas, and there are several urbanized areas (over 95% urbanization) with intense population concentration that challenge the food supply. For Bricas et al. (2017), this set of characteristics has produced a multifaceted set of food distancing, namely (1) geographical distancing, manifested in the remote location of the supply areas from their consumption centers due to the expansion of the urban areas and transport facilities; (2) economic distancing, with the presence of various intermediaries (marketing, processing, stocking, and distribution) between producers and consumers; (3) cognitive distancing, with the loss of consumer contact with the rural, farmers, and mode of production of food, and with knowledge about agriculture mediated by science and the media; and (4) political distancing, manifested in the loss of control of the food system by citizens, which is controlled by a few dominant stakeholders.

These characteristics of the Brazilian food system are not peculiarities of the country; on the contrary, they are recurrent in several social contexts (Intini et al., 2019; Pan American Health Organization, 2018). According to Haddad et al. (2016), about 44% of 129 countries in the world are simultaneously facing malnutrition and obesity problems, and difficulties in access to food and (especially) healthy eating contribute to both phenomena (FAO, 2019). In addition, Sonnino (2019) and IPES Food (2017) point out that the food system, as it is structured and operates, contributes to major problems such as climate change, food waste, food loss, environmental degradation, and the increase of economic inequalities. The current production and consumption model are largely based on the intensive use of nature (expansion of the agricultural area, with intense soil use) and chemical and pesticide products; in the long distances of products and food circulation; in the processing, ultra-processing, and artificial preservation of food; and the concentration of the means of production (land, upstream, and downstream industries of agriculture); and food distribution (supermarkets) (Ioris, 2018, Schneider and Gazolla, 2017; Delgado, 2012; Ploeg, 2008). In this perspective, Sonnino (2019), IPES Food (2017), and Haddad et al. (2016) agree that the hegemonic global food system is failing to feed the population, let alone providing them with healthy food.

It is considering the historical characteristics of the Brazilian food system and taking into account the resulting problems that we will analyze the contributions of the PAA in the next section.

8.3 The construction and execution of the Food Acquisition Program: building food democracy

According to Lang (1999, 218), the food reflects "a titanic struggle between the forces of control and the pressure to democratize." As seen in the previous section, historical elements and contemporary dynamics challenge the construction of sustainable food systems in Brazil. The historic land distribution and economic inequalities and the presence of food empires weaken the autonomy of family farming, drive farmers and consumers away, and intensify the processes of extraction and acquisition of strategic resources such as land, water, genetic material, markets, and so on (Ploeg, 2013, 2008). Due to their unequal and conflictive nature, these dynamics have historically encountered resistance and trigger articulations between family farmers, consumers, social movements, nongovernmental organizations, and so on in building alternative and sustainable food systems. Pervading this conflict and reflecting the disputes present in society and food systems, we find the state historically aligned with the interests of the agribusiness sector and sometimes with ambiguous positions as in the 2000s. As mentioned by Sonnino et al. (2016), the state emerges as a powerful actor given its regulatory power, its gigantic budget, and, not least, its mandate to act in the name of the public interest. From its actions and rules, the state contributes to the construction of more or less sustainable, healthy, inclusive, and democratic food systems.

As Hassanein (2003, p. 79) observes, food democracy brings "the idea that people can and should be actively participating in shaping the food system, rather than remaining passive spectator on the sidelines. In other words, food democracy is about citizens having the power to determine agri-food policies and practices locally, regionally, nationally and globally." In this process, it is important the activism of the actors and the role of the State to promote, encourage, and create spaces for participation and democratization of decision-making and the implementation of public policies.. Thus the building of food democracy is intrinsically related to the breaking of political distancing and the active participation of social actors.

From this perspective, the construction of the PAA shows a process in which organized civil society took an active role in the building and monitoring of food policies, something that is not trivial in Brazilian politics.[6] As soon as he began his first term in 2003, former President Luis Inácio Lula da Silva launched the Zero Hunger Program (Programa Fome Zero), whose construction brought together contributions and lessons learned since the 1990s. During this decade, actors linked to the Workers' Party and/or involved with hunger and poverty issues proposed and implemented various food and nutritional security initiatives, either at the municipal level or at the federal level.[7] In the early 2000s, preparing for the elections, a number of seminars and events were held to discuss issues related to family farming, food supply, and food and nutrition security, all with the participation of social

[6] Grisa and Schneider (2015) mention that the relationship between state and civil society began to change since the 1980s. From critical and vindicatory postures that marked the 1980s, civil society became propositional in the 1980s and, in the 2000s, partner in the implementation and co-management of public policies, such as the PAA. From 2016 on, in a new political context, the relations between state and organized civil society are restructured again, characterized by distancing and conflict.

[7] In the early 1990s, Workers' Party actors craft the document "National Food Security Policy"(Política Nacional de Segurança Alimentar), which called for and recommended the creation of various policies for family farming and food supply, such as the inclusion of family farmers in public procurement and the creation of a National Food and Nutrition Security Council. President Collor's impeachment and national, state, and municipal policy changes offered opportunities for institutionalizing some of these proposals and claims (Grisa, 2012).

movements, academics, NGOs and politicians (Grisa and Zimmermann, 2015; Grisa, 2012). Thus as Menezes (2010, p. 247) mentioned, "(...) elaboration and implementation of the Zero Hunger Program represented the culmination of a whole previous process of formulations and practices in the fight against hunger and for food security in Brazil, experienced by governments (at the municipal and state levels) and social organizations."

Zero Hunger Program was based on the premise of the human right to food and on the realization that it was not being implemented due to the incompatibility of food prices with the purchasing power of most of the population and the exclusion of the poor from the market. To change this scenario, the Zero Hunger Program proposed a set of policies and institutionalities that would act in the scope of food production, income generation, food access, and citizen participation. Among these policies, the Zero Hunger Program presented the idea of articulating public food purchases with the strengthening of family farming and, in terms of institutionality, recreated the National Council for Food and Nutrition Security (Conselho Nacional de Segurança Alimentar e Nutritional [CONSEA]).[8]

As soon as CONSEA was reestablished in 2003, as a direct advisor to the Presidency of the Republic in formulating policies to guarantee the Human Right to Food—a distinction that was unmatched by other Brazilian National Councils—, it began to discuss guidelines for actions in the areas of food, nutrition, and family farming. Government representatives and representatives of the social and union movements of family farming, religious organizations, NGOs, consumer protection organizations, intellectuals, organizations linked to agroecology, and business associations were present in this space.[9] They presented, debated about, defended their conceptions about family farming and food and nutritional security, and contributed to the construction of food policies in a participatory and democratic manner. One of the first works of CONSEA was the document "Food Security and Agrarian Development Guidelines for the 2003/2004 Crop Plan" (CONSEA Technical Subsidies), which presented several propositions that culminated in the creation of the PAA. Thus we could say that the construction of PAA was a collective effort, having as its locus a political meeting place between civil society and state (Grisa and Zimmermann, 2015).

Besides acting in the formulation and building of the PAA, during its implementation, CONSEA (in its national, state and municipal levels) acted in the social control and improvement of the PAA. These roles were performed and manifested in the daily activities of the municipal, state, and national CONSEAS, in the Explanatory Memoranda held by the National CONSEA, in the four National Conferences on Food and Nutrition Security (2004; 2007; 2011; 2015), in the Conferences + 2 years and other activities and actions undertaken by this collegiate organization (Grisa and Zimmermann, 2015). Such spaces allowed decentralizing and democratizing decision-making regarding food policies and the PAA.

[8] CONSEA was created in 1993, in a context marked by the country redemocratization, discussion about the recent promulgation of Brazilian Constitution, the impeachment of President Fernando Collor de Melo and a series of national mobilizations against hunger. However, this Council had a relatively short existence, being extinguished as early as 1995, when Fernando Henrique Cardoso was elected as president of the Republic, and new institutional arrangements and interpretations were attributed to the SAN policy in the country (Maluf, 2007; Takagi, 2006).

[9] Chaired by a civil society representative, CONSEA had a composition of 2/3 civil society and 1/3 government representatives. In 2019, in a new political context, President Jair Bolsonaro again extinguished CONSEA, along with many other spaces for social participation.

Besides the expression of citizen participation through CONSEA (in its different instances), the very dynamics of the PAA implementation shows intense protagonism of civil society. According to the availability of Federal Government resources to the program, throughout the year the National Supply Company (Companhia Nacional de Abastecimento [CONAB]) opens calls for Participation Proposals to family farming organizations. Following the program regulations, family farming organizations (in dialog with other local actors) have the autonomy to articulate and define the participating family farmers, the products that will be marketed (agroecological or not) and the social organizations that will benefit from the food. The supplier and consumer organizations include several social mediators, such as agents of technical assistance and rural extension, NGOs, public managers from different sectors (agriculture, social assistance, planning, and so on), among others. These mediators generally contribute to the program dissemination, the mobilization of the main actors necessary for its implementation, the survey of the production that can be offered, the organization and planning of the production approved by the CONAB project, the articulation with the consumer organizations, supporting the local logistics of the program, providing technical assistance and rural extension, administrative and managerial training of the main actors involved, improving social control, and so on. Once the Participation Proposal has been approved, all implementation (collection and distribution of food) is carried out by the family farming organization in partnership with this set of actors and in dialog with the Federal Government.

Still, in terms of operation dynamics, it is important to highlight that the decisions about the program (modalities, pricing methodology, operating rules, and so on) are the responsibility of a Management Group, made up of representatives of six Ministries. However, in order to increase social participation, in 2012 an Advisory Committee, composed of government and civil society representatives, was established to advise and monitor PAA activities. Scheduled for regular semiannual meetings, the Advisory Committee aims to maintain a dialog channel with social movements and civil society organizations on the implementation of the PAA; to constitute specialized groups on topics for detailing and supporting the decisions of the Management Group; and to suggest improvement in program implementation (Brasil, Grupo Gestor PAA, 2012).

Expressing the articulations between state and civil society in the different levels of the Federation, and the net of social relations built in the territories, the program execution dynamics might be defined as a policy network (Calderón, 2018) that gradually breaks with political distancing by urging social actors participation and protagonism, and, at the same time, breaks the economic distancing, when creates a direct dialog between producers and consumers. During the program operation, the state was sensitive to the demands of social participation and democratization of food policies, although not without conflicts and tensions[10] (Grisa and Zimmermann, 2015). Openness to dialog and social participation illustrates the exercise of food democracy, whose manifestation is not linear, evolutionary, and stable; on the contrary, it expresses the political struggles present in the food system. The extinction of CONSEA in 2019 and the PAA's own political, economic, and social

[10] Not all CONSEA interpretations, demands, and proposals in relation to the PAA have been met by the Federal Government and implemented in local spaces. The ideas and demands established in CONSEA enter the process of dispute, selection, and negotiation with the ideas and interests built by other social actors, and their institutionalization depends on the degree of conflict, the agreements established, the institutionalities present, and the policy dynamics (Grisa and Zimmermann, 2015).

FIGURE 8.1 Food production from a quilombola community for Food Acquisition Program. *Source: Grisa, C., et al., 2015. Governança e performance do PAA: um estudo comparativo entre Rio Grande do Sul e Rio Grande do Norte (relatório de pesquisa).*

weakening (discussed below) show the fragility of food democracy.

8.4 Food Acquisition Program and the building of sustainable food systems

As previously noted, the unequal agrarian structure and the privileged treatment of medium and large producers, historically granted by the state, are striking features of rural Brazil. In this sense, one of the PAA's great innovations was to support the commercialization of family farming. Indeed, following the trajectory of the differentiated credit policy created in 1995 (PRONAF), the PAA became the first public procurement policy with an exclusive focus on family farming, explicitly connecting it with food and nutrition security. It should be noted that within the category of family farming are land reform settlers, landless rural workers, campers, quilombolas,[11] agro extractivists, dam-affected families, and indigenous communities. In addition, over time, institutional incentives were created in the program to promote and increase the participation of women and family farmers in greater social vulnerability (beneficiaries of Family Grant Program—Programa Bolsa Família)[12] (Brasil, Presidência da República, 2013, Brasil, Grupo Gestor PAA, 2013a, b, 2011). Unlike the hegemonic food system oriented toward economic concentration and social exclusion, PAA dialogs with and values the diversity of social groups in family farming, and promotes gender equality and socio-productive inclusion, key elements in promoting food security and building sustainable food systems (Bricas et al., 2017) (Fig. 8.1).

In order to promote the participation of family farmers in public food purchasing, PAA waived the use of bids, provided that the prices are not higher than those practiced in the regional market. This is an important institutional innovation, as the Bidding and Administrative Contracts Law (Lei de

[11] Living in temporary settlements, most quilombolas descend from the African slaves who were shipped to Brazil at the beginning of the 16th century to work on plantations until the abolition of slavery in 1888.

[12] Regulations began to require minimum percentages of women's participation in PAA Participation Proposals, as well as allocating part of the budget specifically to women's organizations. In addition, priority should be given to farmer suppliers enrolled in the Federal Government's Single Registry for Social Programs (Cadastro Único para Programas Sociais do Governo Federal), beneficiaries of Family Grant Program and other productive inclusion programs.

Licitações e Contratos Administrativos—Law No. 8666 of June 21, 1993) restricted the participation of most family farmers in the institutional market, due to the competition with business segments, usually organized from higher production scales and lower production costs.

Unlike the hegemonic agri-food system, PAA promotes the acquisition of a diverse set of foods, resulting from the diversified demand and the opportunity for farmers and their organizations to offer what they have to market if agreed on the trading projects. In 2012, the year of the largest execution of the program, 529,033 tons of food were acquired, including fruits, juices and fruit pulp, vegetables, milk and dairy, bread, fish, cereals and legumes, poultry and eggs, coconuts, nuts and walnuts, among others. A wide range of products can be purchased from the same family unit, many of them previously produced without commercial destination, restricted to those spaces of family consumption and to the reciprocal relations. They are often typically products for own consumption, for household subsistence, grown in small quantities, in areas close to home or not used for the main commercial crops (Siliprandi and Cintrão, 2014). According to Siliprandi and Cintrão (2014, p. 119), "there are cases where the PAA creates (or recreates) outlets for products that were on the fringes of hegemonic markets, which were being left aside by many families." This means the rescue and the preservation of the many regional products, customs, habits, cultures, and identities that have been forgotten over generations, often because of their conception of being "outdated" and/or as a result of a growing process of commodification of agriculture (Ploeg, 1992), which affects event the sphere of food production for their own consumption (Gazolla, 2004). It is about the rescue and valorization of foods associated with culture, identity, and territories, the basic principles of food and nutritional security (Fig. 8.2).

In addition to resuming and stimulating productive diversification, the PAA also contributed to increasing the production for own consumption and the food and nutrition security of rural households (Ghizelini, 2010). In research on four agrarian reform settlements in different Brazilian regions, Schmitt et al. (2014) observed that the PAA increased the production for self-consumption, either by promoting the consumption of garden and backyard products, previously undervalued or by diversifying this consumption from the demands of the institutional market. In a survey on the PAA, conducted in 2014 in the Pelotas, Rio Grande do Sul

FIGURE 8.2 Production of vegetables for Food Acquisition Program. Source: *Grisa, C., et al., 2015. Governança e performance do PAA: um estudo comparativo entre Rio Grande do Sul e Rio Grande do Norte (relatório de pesquisa).*

region, we also observed the increase in the value of products intended for own consumption, which could be either consumed or traded. Even families who, for various reasons, had stopped trading for the PAA, continued to produce for own consumption with higher quality. According to a rural extension worker interviewed, "Even the one who left the group [no longer sold to PAA] has the garden and it is ecological. The things they eat are green. They keep doing the things they are supposed to eat, and that has changed a bit in the farmers too. (...) the things they eat are all ecological, which was not before. They planted, didn't even actually plant, because many people did not have the habit of planting kale and today they do." (Grisa et al., 2015). Similarly, Mielitz (2014, p. 67) points out that "several products previously abandoned from everyday food practice because they are not considered modern, especially by the younger ones, are once again consumed." Indeed, in a recent survey in the region of Chapecó, Santa Catarina, we observed that rural households that accessed the PAA and the National School Feeding Program had higher monthly production for own consumption (around R$ 1000.00 and R$ 1150, respectively) to the others (R$ 800.00 and R$ 740.00, successively) (Grisa et al., 2019). Although the production for own consumption does not meet all quantitative and qualitative nutritional demands, the strengthening of this strategy is generally associated with food autonomy and the promotion of food and nutritional security.

It is also important to highlight that PAA stimulates agroecological and organic production paying up to 30% more to productions with this management in relation to products from conventional agriculture. As mentioned by Moreira et al. (2010, p. 210), this price differential aims to promote "another technological matrix based on the production of clean, healthy, pesticide-free foods, which respects the diverse lifestyles of rural populations, strengthening the food culture of each region and the maintenance of sociobiodiversity." Indeed, many studies report the promotion of agroecology, the transition to agroecology or the reduction in the use of pesticides (Mesquita and Bursztyn, 2017; Grisa et al., 2015; Schmitt et al., 2014). It is important to consider, however, that only foods that have an organic or agroecological certification or other compliance verification mechanisms established in law receive 30% more than the normal price. Due to these rules and the difficulties in organizing family farming, many family farmers produce agroecologically and sell as conventional food to the program, (Schmitt et al., 2014; Schmitt and Grisa, 2013), impacting official statistics that indicate participation of organic and agroecological products between 1% and 3% of total acquisitions (Galindo et al., 2014).

PAA also contributes to the sustainable extraction and exploitation of several products of socio-biodiversity. Brazil nuts, babaçu coconut, pequi, mangaba, native fruits, açaí, cupuaçu, and pine nuts are some products of socio-biodiversity contemplated and valued by the program. In Minas Gerais, Carvalho (2007) observed a 300% increase in the sale of a cooperative that produced frozen fruit pulps, part of which comes from the extractive collection. Through the program, part of this food was donated to local schools, strengthening ties in families and the community, and transmitting the appreciation of native biodiversity to future generations. In the state of Acre, in the Amazon, before the establishment of the PAA program, Brazil nut extractivists depended entirely on the market opportunities provided by brokers, who would mostly buy the nuts below their market value. Under the PAA program, extractivists have sale assurance of their products and have seen the price of the nuts increase, benefiting the set of farmers inserted in this productive chain. (Schmitt et al., 2014). According to Mota and Schmitz (2015), PAA provided opportunities for insertion in the markets, the enhancement of identity and the recognition by the state of Mangaba Fruit-Picker Women, a group traditionally weakened due to difficulties in accessing mangaba in private properties. When these foods and products are valued, they make those who produce them visible, provide foods with high nutritional value, and rebuild agriculture and the agri-food system with nature and agroecological processes (Mota and Schmitz, 2015; Schmitt and Grisa, 2013; Petersen, 2009; Carvalho, 2007).

Despite PAA's contributions to the environment and socio-biodiversity, Mesquita and Bursztyn (2017) state that this relationship could be improved. According to the authors, in 2012, Brazilian semiarid region experienced the greatest drought in the last 50 years, and the performance of programs such as the PAA, the One Million Cisterns Program (Programa Um Milhão de Cisternas), and social policies were essential to reduce the historical hunger, poverty, and violence caused by the scarcity of production. "Even though local production was impacted by the drought, social unrest, looting of storage facilities or people begging in the streets were not observed as they used to be in the past" (Mesquita and Bursztyn, 2017, p. 1045). The program's performance offered support and means to endure adverse weather conditions. However, in the authors' assessment, farmers, beneficiaries, and the community would need to better understand the implications of phenomena and climate change. For the authors, it is necessary to "incorporate the environmental sphere into social strategies that have been proved to be of great success in vulnerable areas of developing countries. Social protection programs have the potential to enhance farmer adaptive capacity to deal with climate change, but can also be impacted by the same environmental stressors" (Mesquita and Bursztyn, 2017, p. 1048). It would be important to incorporate the debate (still absent) on climate change in the PAA, discussing the effects of agricultural production models on sustainability, and how the adaptation strategies already present in the program (although not visible) could strengthen family farming in severe climatic situations.

Regarding the subject of consumption, the program contributes to meeting the Human Right to Food, especially of people in socially vulnerable situations. Formally established organizations may receive food and supply them directly to consumers or, in specific cases, may pass them on to accredited entities (Brasil, Grupo Gestor PAA, 2018). The organizations formally licensed to access the program are those linked to the Social Assistance Network (Social Assistance Reference Center, Specialized Reference Center for Social Assistance, Specialized Reference Center for Homeless People, and others), food and nutrition equipment (popular restaurants, community kitchens, food banks), and authorized governmental and nongovernmental entities. In turn, the beneficiary consumers are individuals in the situation of food insecurity, helped by these organizations (Brasil, Grupo Gestor PAA, 2018). In 2012 PAA served more than 23,800 social assistance organizations across the country, estimating the food availability for 22 million people. According to Campos and Bianchini (2014, p. 20), "The coverage of these institutions reached almost 3000 municipalities, that is, more than half of all Brazilian municipalities already had products from family farming to the supply of their food and nutrition equipment (Fig. 8.3)."

As mentioned, through the program, a wide range of food is purchased from family farms and passed on to social assistance entities. In 2012 the year with the highest execution of the program, CONAB acquired 380 types of products, 22% of which were vegetables, 19% processed food (breads, cakes, cookies, and so on), 17% fruits, 15% dairy, 11% grains and oilseeds, and 7% meat and others (Brasil, CONAB, 2012). Fruits and vegetables accounted for almost 40% of the whole, predominating the consumption of fresh and minimally processed foods, which are associated with the promotion of healthy eating (Pan American Health Organization, 2018; Brasil, MS, 2014) (Fig. 8.4).

FIGURE 8.3 (A) Buying food in a quilombola community. (B) Donation of food in an urban community. *Source: Grisa, C., et al., 2015. Governança e performance do PAA: um estudo comparativo entre Rio Grande do Sul e Rio Grande do Norte (relatório de pesquisa).*

FIGURE 8.4 Food distribution in an urban community. Source*: Grisa, C., et al., 2015. Governança e performance do PAA: um estudo comparativo entre Rio Grande do Sul e Rio Grande do Norte (relatório de pesquisa).*

In many situations, social entities and consumer families were not used to eating certain healthy foods or were unaware of preparations using such ingredients (Procedi, 2019; Grisa et al., 2015). A manager who took part in the implementation of the PAA in São Lourenço do Sul mentioned that, at the beginning of the program, the beneficiary consumers were surprised by the types of food distributed, for they were accustomed to the composition of baskets (processed foods) that the town hall previously distributed through another social policy. According to the manager, the replacement of processed foods by fresh products (vegetables, fruits, fish, and so on) from the PAA was difficult, demanding dialog, workshops and courses on good food practices with communities and beneficiaries, and "today, you hardly see anyone complaining that there is no coffee, no sugar, no oil"(Grisa et al., 2015). Similar to this case, there were workshops on good food practices, food use, and food education, often organized by the social assistance organizations themselves or by mediation organizations in other contexts of the country, seeking to promote healthy eating and to bring consumers closer to food, local production, and regional food roots.

It should be noted that the amounts of food received by consumers through the program are not enough to meet all their nutritional and food needs. Usually, the receipt of food (variables according to each trading proposal) occurs weekly or every 15 days, and they can be consumed in preparations made by the receiving organizations or intended for individual household consumption. In 2014 in the municipality of São Lourenço do Sul-Rio Grande Sul, once a week (every Tuesday), the beneficiary families received 5 L of milk and 2 L of dairy beverage, and every 2 weeks the families received 1 kg of beans, 1 kg of rice, and fruits and vegetables (Grisa et al., 2015). In the consumer's assessment, food was "good," complemented the family diet, and provided frequent access to fruits and vegetables (something not always possible if access to food depended on markets) (Grisa et al., 2015). Procedi (2019) reports on the relationship between the PAA and eight social assistance entities in the Rio Grande do Sul, and, in all cases, the program's food helped to complement the foods that the entities had. Fruits, vegetables, juices, baked goods, juices, cornmeal, and rice were some of the products received weekly or biweekly. According to the author, one of the entities reported that fruits and vegetables were essential to complement the meals offered, contributing to the food and nutritional security. In another entity, which received rice and grape juice, the understanding was that, although not diversified and insufficient, PAA's food allowed the family to use the resource previously spent for rice for other needs. Thus although insufficient in terms of quantities, the PAA contributes to the access to and the better availability of food.

By reconciling the demands of family farmers with the food and nutritional security needs of socially vulnerable individuals, PAA connects production and consumption through short supply chains (Gazolla and Schneider, 2017; Schmitt and Grisa, 2013). These are usually social assistance organizations or entities located in the same municipality as family farming organizations or in nearby towns, avoiding long distances between them, and, also, relations between producers and consumers are not mediated by economic intermediaries. These important elements contribute to reducing the geographical and economic distancing present in the hegemonic food system.

Moreover, instead of food that "comes from nowhere," grown by unknown producers, produced in a standardized way, packaged, and transported over long distances by various intermediaries or large corporations (Schmitt, 2011), regional foods and family farming gain visibility and recognition. Usually, the farmers deliver personally their food to the social assistance organizations or the public nutrition equipment, which helps to minimize cognitive distancing. In research in São Lourenço do Sul (Grisa et al., 2015) (the same was observed by Procedi, 2019), it is evident that representatives of social assistance organizations generally have a good understanding of how the program operates, what is food origin and what is their differentiated quality. However, this understanding not always reaches the consumers' families, an issue that demands improvement in the program (Grisa et al., 2015). Aware of this limitation, in some social contexts, social assistance organizations and mediation organizations took customers to visit family farming cooperatives and to some rural families, aiming to approximate the urban consumption and rural reality (Grisa et al., 2015). If understanding the rural dynamics is important, Fróes et al. (2007) also report the importance of family farmers knowing the reality of urban peripheries. For the authors, "The delivery made directly by farmers and fishermen, leaders and rural leaders provided moments of exchange of ideas with people from the periphery. Farmers, interacting with the residents of the poorer villages and neighborhoods, began to understand their reality, creating bonds of solidarity." (Fróes et al., 2007, p. 51). These bonds and understanding help to minimize cognitive distancing related to food origin, family farming specificities, and urban dynamics.

All these PAA elements and outcomes contribute to different dimensions of food and nutritional security (access, availability, healthy and culturally appropriate food, and so on), and stimulate dynamics that contribute to the building of sustainable food systems. With the same public resources, it is possible to promote social inclusion and strengthen family farming, to contribute to more sustainable production and distribution practices, to promote access to healthy food, to encourage food education, and to strengthen community and local ties. These systemic effects, integrated and directed to changes in the hegemonic food system, attracted the attention of academia and political and institutional spaces at the subnational and international levels. For Nehring et al. (2017, p. 6), the experiences of PAA, PAA Africa and Purchase for Progress (P4P) indicate that "Institutional Demand programs can be essential tools for governments to extend favorable markets to smallholders and establish social protection networks that promote food security." According to FAO (2017), public procurement, such as the PAA, offers the opportunity to support family farming, stabilize markets (supply or price crises), and provide healthy food for food and nutrition security initiatives, such as school meal programs, popular restaurants, food aid programs, among others. "Thus, family farming purchases take a 'double-way' approach: in the short term they provide income to producers and food to social programs, while in the long run they consolidate family farming, foster increased food availability and ensure healthy and nutritious eating for the vulnerable population"(FAO, 2014, p. 117). In the words of Sonnino (2019, p. 21), "Public procurement (. . .) is becoming increasingly recognized as a tool to address some of the challenges of an unsustainable food system (. . .). There is growing recognition of the 'power of purchase' to foster a healthier food system and link issues of public health, economic development, democracy and environmental integration."

In the next section, we are going to return to the program's national trajectory, to outline some recent challenges, and to analyze possible convergences between PAA repercussions and the country's internal dynamics.

8.5 Food Acquisition Program discontinuity and the weaknesses for sustainable food systems and food and nutrition security

Broadly speaking, PAA presented a growing trajectory of political recognition, applied resources, family farmers, and beneficiary social assistance organizations from 2003 to 2012, the year in which the program performed the best on its history. In 2003 PAA invested approximately R$ 145 million, and in 2012 this amount reached a total of R$ 838 million, the highest value applied by the program. In absolute terms, the number of family farmers supplying rose from around 150,000 in 2006 to just over 185,000 in 2012. Although growing, these numbers mean little given the size of the Brazilian rural area, for the program reached only 4.2% of all family farmers (Mielitz, 2014).[13] In relation to resources, they remained insufficient due to the intense demand manifested by family farming social and union movements and by organizations linked to food and nutrition security (Grisa and

[13] Several studies carried out over the 10 years of the Program point out that it can indirectly benefit a larger farmer public, either by the possible increase in product prices for other local/regional farmers, or by promoting/creating other markets or marketing channels, or for the commercial appreciation of products that were not "appreciated" or demanded in "traditional" marketing circuits (Delgado, 2013; Pandolfo, 2008; Delgado et al., 2005).

Porto, 2015). Although "small," there is a widespread understanding of PAA's contributions to food and nutrition security and the building of sustainable food systems (Swensson, 2015; Porto, 2014; FAO, 2014; Delgado, 2013).

However, since 2013 the program has been undergoing a process of political, economic, and social weakening, emphasized since 2016. In 2013 the resources applied, the numbers of beneficiary family farmers and social assistance organizations, and the amount of food purchased practically halved if compared to 2012 (Table 8.1). In 2017 the resources invested, the numbers supplying of family farmers, and the quantity of food purchased accounted, respectively, for 22%, 16%, and 11% of the 2012 figures. In 2018 CONAB executed the lowest value (R$ 63 million) since the beginning of the program (Brasil, CONAB, 2019). Although accounting for only part of the amount executed (the information for the rest is unavailable), this amount (added to the other figures presented) serves to exemplify PAA's political devaluation and financial and operating deconstruction (Table 8.1).

Several factors contributed for this situation: (1) the execution of the PAA became more intense in formal rules and, at the same time, the program supervision became more intense and less flexible, causing the program to stop in

TABLE 8.1 Resources invested in reais (R$), number of beneficiary family farmers, number of beneficiary social assistance organizations, and amount of food purchased (kg) by PAA from 2011 to 2017—Brazil.

	Resources applied (R$)	Number of supplying farming families	Number of beneficiary social assistance organizations	Food purchased (kg—tons)
2003	145,014,750.90	41,464	[a]	7,800
2004	181,074,211.46	68,697	[a]	248,804,68
2005	295,582,051.59	69,692	[a]	277,033.48
2006	497,833,620.40	150,919	[a]	462,598.69
2007	465,105,404.51	134,574	[a]	418,661.22
2008	512,036,873.93	138,285	[a]	396,379.94
2009	591,244,764.73	142,381	[a]	500,490.78
2010	675,133,142,78	157,594	[a]	462,429.16
2011	667,325,490.15	160,011	25,331	517,921.88
2012	839,217,997.38	185,979	23,866	529,033.66
2013	443,185,235.52	96,912	12,329	280,175.45
2014	583,838,845.62	113,727	13,225	336,155.54
2015	555,429,848.06	95,871	14,065	289,827.17
2016	417,407,933.74	76,896	14,772	133,909.94
2017	191,135,350.62	31,187	4,720[b]	59,115.82

[a] *Data unavailable.*
[b] *Incomplete information.*
Author elaboration from PAADATA (public data) and Brasil, Ministério Do Desenvolvimento Social E Combate À Fome, 2010. Programa de aquisição de alimentos—PAA. MDS (Caderno base III Seminário Nacional do PAA), Brasília.

several contexts, and there were cases of criminalization of family farming organizations, which in turn generated legal uncertainty in the program implementation; (2) requirements for product compliance to health surveillance standards became stricter, which also meant the halting of program implementation in some social contexts; (3) institutional changes in the program made it difficult for less structured family farmers to participate; (4) the emergence of new public procurement opportunities for family farming; (5) the economic and political crisis experienced by the country in recent years, followed by changes in political orientation; (6) the change in understanding of the role of family farming and food and nutrition security in the country's development, examples of which are the abolition of institutions dedicated to food security (such as CONSEA) and family farming (such as the Ministry of Agrarian Development) and the dismantling of various policies for family farming (Procedi, 2019; Sabourin et al., 2018; Sambuiche et al., 2019; Grisa, 2018; Porto, 2014).

Since 2016, new actors, political positions, and interpretations have started to guide Brazilian politics, and since 2018, the ultra-right has gained more institutional space (Rocha, 2019). Since then, conservative and authoritarian values and economic guidelines have prevailed in the actions of the state and in the interpretation of the role of the rural, the environment, and food and nutrition security (Vasconcelos et al., 2019; Grisa, 2018). According to Sabourin et al. (2018), in addition to the context of the international economic crisis, it is possible to say that the political change from 2016 shifted back to agribusiness, the main focus (which had already been strengthened in the 2000s) to the detriment of family farming policies and the food system it involves. As stated at the beginning of Section 8.3, the forces of the food system are in tension (and the state plays its part here) fighting for more or less sustainable, healthy, inclusive, and democratic trajectories and dynamics. In this new scenario, several indicators designate challenges for the PAA, food and nutritional security, food democracy, and the construction of sustainable food systems (Mello-Théry, 2019; Vasconcelos et al., 2019; Le Tourneau, 2019). It is noteworthy that the visibility and recognition of the program at the national and international levels were not sufficient or did not produce effects for its national strengthening. Indeed, world views and political understandings within the country were prevalent in redefining the program's trajectory and weakening it politically, economically, and socially. Although the dynamics of the PAA are still a reference and a "model" to be disseminated to other contexts, especially by international organizations, such movement is not echoed in the Brazilian political and institutional sphere.

This scenario of political and economic weakening of the PAA implies the discontinuity of many food-marketing projects that connected producers, consumers, and social mediators. Procedi (2019) analyzed the repercussions of this discontinuity for family farming cooperatives and for social assistance entities in the Rio Grande do Sul. According to the author, the PAA contributed to the structuring and organization of cooperatives, strengthened associative, generated productive improvements and increased income, promoted autonomy from middlemen, and valued female work, and the presence of young people. However, with the PAA paralysis, there were cases of abandonment of agricultural activity, closure of agro-industries, intensification in other public purchasing channels, and the resurgence of middlemen, once again establishing the economic distancing between producers and consumers (Procedi, 2019). In the Pelotas region, we observed that the PAA discontinuity caused a loss of production and financial resources for family farmers, intensified their relationship with middlemen, and generated discredit in family farming cooperatives (Grisa et al., 2015). Analyzing the program interruption in Paraná in 2013, Zimolog (2015) observed reduced production, increased pasture, decreased diversification, uncertainty, and discouragement for family farmers. According to the author, in some cases, the Family Grant Program has become the main income of the family. From these cases, it is possible to affirm an increase in the fragility and vulnerability of family farming and the strengthening of the hegemonic food system.

Regarding social assistance organizations, food supplementation with the PAA has provided "surplus money" for investment in infrastructure and expansion of service, and improvements in food quality through the promotion of healthy eating habits, with fresh, local, and agroecological products (Procedi, 2019). The program halt induced cases of suspension of works or of expected structural improvements, decrease in attendance and, in some situations, interruption of activities involving food distribution (Procedi, 2019). Analyzing a similar situation in Pelotas, we observed that the discontinuity of the program led to a paralysis in the access to certain foods (mainly fruits and fish), compromising the quality of the food consumed (Grisa et al., 2015). Given the PAA discontinuity, some social entities returned to carry out campaigns to collect and donate food and reported the intensification of the search for the Family Grant Program by the beneficiaries. Important aspects of food and nutritional security have been compromised.

8.6 Final considerations

As discussed in this chapter, PAA makes important contributions to food and nutrition security and the construction of sustainable food systems. The program provides access to healthy (albeit insufficient in quantity) food, which enhances local cultures and territories, is produced based on more sustainable food practices, and values family farming. In its building process and given its organizational dynamics, PAA contributed to minimizing the political, geographical, economic, and cognitive distancing characteristic of the hegemonic agri-food system. Its construction and execution involve protagonism of organized civil society and a wide range of actors interacting in a network, comanaging and participating in public policy with the state; its territorial execution dynamics allows the valorization of production and local actors, minimizing large displacements and intermediations between producers and consumers; and there is an effort to connect the origin of food and food to territories, the natural processes, and their specific mode of production. With the same financial resources, it is possible to act in an intersectoral way, promoting family farming, healthy eating, health, the environment, and local/territorial development. These characteristics promoted sustainable food systems that attracted the attention of academia and political and institutional spaces in Brazil and internationally.

However, this international recognition does not correspond to the political and financial devaluation of the program at the national level. Since 2013, and, more sharply, since 2016, PAA has been undergoing a process of political, economic, and social weakening or dismantling, with a significant reduction in the financial resources applied and in the numbers of family farmers and beneficiary social assistance entities. Several factors contributed to this process, notably the change in the country's political orientation since 2016 and notably in 2019. In the titanic struggle between forces to control and demands for democratization of the food system, family farming and food security and nutrition were minimized to the benefit of the agribusiness sector. The historical roots of the

Brazilian food system are returning strongly, threatening important changes in the last two decades.

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CHAPTER

9

Food and nutrition security and wildlife conservation: Case studies from Kenya

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9.1 Introduction

Food and nutrition security has been debated and discussed all over the world for a long time. Many ideas and policies have been suggested by world leaders to reduce hunger and food insecurity in the world such as Millennium Development Goals (UN-SCN, 2010) and UNDP (2015). Despite all these efforts food and nutrition security is still a challenge in the world today, more so in the developing countries (FAO et al., 2018). Food and nutrition security is achieved at all levels (both at the individual, household, regional, and global) when all people have physical and economic access to adequate, safe, and nutritious food (FAO, 1996). From its definition, food security has four dimensions (Gina, 2003; FAO et al., 2018):

- Availability of adequate quantities of food of good quality is made available using various means such as domestic production, trade, stocks, and transfers (which include food aid by various organizations, for example, donors and African governments).
- Both physical and economic access to food at the household and individual level is mainly through farm production, whereas others access food by purchasing from the local markets and through a cultural exchange such as barter trade or gifts from family members and the community.
- In order for food to be used by the body optimally, there is a need for intake of nutritious food supplied through a well-formulated diet, which includes clean water and proper sanitation.
- Continuous sustainability of the above three—the nutrition aspect and food preferences are important to food security, so is the ability to have stable access and

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capacity to utilize the available quality food, supported by a clean environment and proper adequate sanitation and efficient health services (Alders and Kock, 2017).

When all these dimensions of food security and nutrition are considered, achieving food security in most developing countries has been an uphill task, and many countries have not been able to achieve it. For example, the achievement of food and nutrition security in most developing countries such as Kenya has remained a mirage on a distant horizon. According to a report on nutrition status among 47 countries, members of the World Health Organization (WHO) Africa region, the proportion of children (under 2 years of age) receiving a minimum acceptable diet was low in Benin and in Kenya (WHO, 2017). Millions of people in Kenya suffer from chronic food insecurity and poor nutrition, and many more (between two and four million people), especially in the arid and semiarid areas, require emergency food assistance (Republic of Kenya, 2011). Even in years of good on-farm production, poor nutrition (stunting) still affects 30% of children in Kenya. This shows that there is a long term insufficient dietary intake of food (both macronutrients and micronutrients). Food insecurity is worsened by an inadequate distribution of high-quality foods, lack of knowledge about feeding by mothers and caregivers of young children and lack of prevention of infectious diseases, and poor medical services in rural areas (Republic of Kenya, 2009a,b, 2011). This situation is even direr for people who live in arid and semiarid lands (ASALs) where agricultural food production is affected by climate variability and human−wildlife conflicts (HWCs).

Many advances have been made in agriculture in most countries of the world, but food insecurity in most countries has continued to persist (FAO et al., 2012). Over a third of the human population in developing economies is affected by micronutrient deficiencies. Malnutrition is a multifaceted problem and spans across a number of sectors and occurs in both developed and developing countries. In developed countries, it manifests in overnutrition (obesity) or undernutrition (micronutrient deficiencies). However, in developing countries, poverty is a major driver of food and nutrition insecurity (World Bank, 2008a). Deficiencies in certain nutrients such as vitamin A and trace elements such as iron and zinc contribute to increased diseases and mortality in women and children in poor countries in Africa (Brown et al., 2009; World Bank, 2008a). According to FAO (2014), there are high malnutrition incidences in Africa with one in four people estimated to be undernourished. The situation is aggravated by inequitable household power relations where women have limited access and control of production resources (Nyongesa et al., 2016a, 2016b; Meinzen-Dick et al., 2011).

The UN Environment 2019 observed that despite increased technological advances over the last century, more than 90% of crop varieties and half of the domesticated animals have disappeared from agricultural fields and the world's 17 main fishing grounds are at or above the sustainable fishing limits (UNEP, 2019). This narrows the human dietary diversification options amid an increasing world population. The decline in species and the increase in the human population put pressure on the available resources and contribute to the fragmentation of existing ecosystems as people clear out more land for habitation (UNEP, 2019). This trade-off between food production (in search of food and nutrition security) and ecosystem and hence wildlife conservation have existed for ages. It is the more vulnerable people who end up clearing the available land, often near wildlife habitations (Alders, 2009). Whereas the land expansion assures human populations of increased food production in the short term, the expected impact on food and nutrition security, including a reduction in malnutrition levels among vulnerable groups has not been achieved (Alders and Kock, 2017; Teja et al., 2012).

In this chapter, we provide a link between wildlife conservation and food and nutrition security, using case studies from Kenya. The manuscript is organized as follows: Section 9.1 gives the introduction, Section 9.2 gives a literature review, Section 9.3 gives case studies from Kenya, and Section 9.4 discusses imperatives and challenges.

9.2 Literature review

9.2.1 Definitions

9.2.1.1 Wildlife

"Wildlife" refers to the undomesticated animals and uncultivated plants living in their natural habitats such as forest, grassland, ocean, lake, river, stream, and desert, without the influence of human activities (Sharma et al., 2014). In the context of this chapter, the term "wildlife" refers to wild animals, wild birds, and "flora" in general.

9.2.1.2 Wildlife conservation

Wildlife conservation is the practice of protecting wild species (plant and animal) and their habitats in order to ensure that the wildlife is preserved and prevented from becoming extinct. Earlier works by various authors such as Giles (1978) described wildlife conservation and management as a science and art of making decisions and using natural resources to conserve wildlife and manage them well to eliminate threats to the existence of wild flora, fauna, and their habitats for improved human welfare, present, and future. Most threats to wildlife are mainly human imposed and include but not limited to: habitat destruction/fragmentation, overexploitation of natural resources, pollution of the environment, and climate change (Sharma et al., 2014). A key challenge facing the world today is how to meet the need for sufficient, safe, and nutritious food without exhausting the natural resources available (FAO, 2014). According to Tidball (2014), *maintaining a stable ecological balance and human quality of life are both dependent on wildlife*.

Wildlife conservation, therefore, has direct and indirect contributions to food and nutrition security. Wildlife, as a direct and basic benefit, is a food resource to many households either as a primary source of animal protein or vegetables/fruits/medicines/veld products such as honey or as luxury/delicacy food (Golden et al., 2011). In many world cultures, wild animals are an integral part of cultural diets. Studies show that wildlife was a major contributor to food and nutrition security for people living in African countries. Consumption of wild animal and plant products contributes to improved health and income of households (Cooper et al., 2018; Golden et al., 2011). Illegal hunting, overhunting, and encroaching into the wild animals' natural habitat have led to declining animal populations, hence affecting food security in such regions. Encroaching too close to their natural habitat has also led to the destruction of agricultural fields. Sustainability of the direct benefit of wildlife is therefore dependent on the existence and implementation of government policies/controls and/or cultural prohibitions. Without controls, and with the devastating effects of climate change on agricultural food production, HWC is apparent as humans use technological advances in hunting, and the wild animals attack human beings and livestock and destroy crops.

9.2.2 Why wildlife conservation

Conservation of wildlife has become a necessity in order to preserve organisms in the wild, which might be faced with extinction as a result of human activities such as hunting and destruction of wildlife habitats due to the increasing human population in the world. As the human population increases, there is an increased demand for more food, leading to the expansion of farming into wildlife areas or unsuitable lands such as the ASALs. This expansion may lead to the destruction of wildlife landscapes further jeopardizing food and nutrition security. The various policies and legislation enacted to conserve wildlife may limit access to wild food supplies by communities, resulting in food insecurity to many rural households located in the conservation areas. Therefore there is a need for a holistic approach to farming, which should include methods to preserve wildlife and biodiversity.

9.2.3 Loss of biodiversity

With increasing human population, encroachment on wildlife areas by clearing of forested land to grow food crops has led to a loss of biodiversity. The contribution of wild plants and animals to household food diversity may be reduced as biodiversity is lost, and humans are no longer able to meet their protein requirements especially communities bordering conservation areas. In order to preserve wildlife, governments enact laws that try to keep people out of the conservation areas. However, it is imperative that instead of considering biodiversity as exclusive, successful food production and biodiversity conservation need to be considered as interconnected. This holistic view of agricultural production and biodiversity conservation could lead to better management of natural resources (Smith and Haddad, 2015; Burlingame and Dernini, 2012; Frison et al., 2006). Therefore to achieve sustainable food and nutrition security, novel methods and policies of integrating food production and biodiversity conservation are required in many developing countries of the world (Sunderland, 2011; Chappell et al., 2016; Wittman and Blesh, 2015).

Agricultural production has an impact on biodiversity, and hence a holistic approach will deliver better results ensuring sustainable and ecologically sound food production systems. Certain individuals particularly women and girls who have limited access and rights to production resources face threats to food and nutrition security. In turn, these groups are a threat to biodiversity as they attempt to acquire food from the limited natural resources at their disposal. These will further increase the destruction of biodiversity, leading to unstable food systems (Schipanski et al., 2016; Chappell and LaValle, 2011). Due to the nature of agricultural production that is mainly carried out at the household level and mainly on smallholder farms in Africa, issues of gender equality and justice need to be taken more seriously to avoid negative impacts of agricultural production on biodiversity (Stone, 2002). Gender mainstreaming in agricultural production systems is necessary to enable more sustainable food systems to be developed. For food systems to be sustainable, all genders should have equal access to resources for production such as land and capital (Liu et al., 2007). Men and women in agricultural households make decisions that impact on labor provision as well as the adoption of new technologies, which in turn affect natural resource utilization and agricultural productivity. Also, the proceeds from the sale of agriculture produce go to the one controlling resources of production who are mainly men, and this implies that most women in rural areas do not have income. It has been documented that when women have income, they allocate more to food, health, and education of their children. This leads to improved welfare at household level (Sweetman, 2012). The role of women in food production, utilization, and biodiversity conservation needs to be reexamined and emphasized.

9.2.4 Food security and wildlife conservation

Wildlife conservation contributes to all four aspects of food and nutrition security discussed earlier. Most households in rural regions are depended on land and related natural resources for survival. In some communities living close to protected areas, there has been encroachment on wildlife habitats, leading to overexploitation of the natural resources and HWCs. Some poor communities living close to protected areas have moved into these areas to obtain food and other naturally occurring products to supplement their food requirements. For example, some communities in Central Africa obtained most of their protein requirements from hunting wildlife in gazetted forest areas (Sharma et al., 2014). To sustain their lifestyles, there is a need for controlled offtake of wild animals in these regions so that this resource can be conserved and thus be available to future generations.

The conservation, enrichment, and utilization of biological diversity are the prerequisites for the sustainability of the agricultural sector. Food security cannot be detached from the primary source, that is, productive land and marine ecosystems, whether wild or managed (Millennium Ecosystem Assessment, 2008; Frison et al., 2006; Lockie and Carpenter, 2010). Overlooking the intricate dependencies implies that although the outcome of the MDGs indicated that globally at least 805 million were experiencing extreme, chronic malnourishment between 2012 and 2014, the actual hunger due to lack of micronutrients is higher, and often results from delinking food and nutrition security from biodiversity conservation and utilization (FAO et al., 2012). Micronutrient deficiencies affect more than a quarter of the world's population (IFPRI et al., 2013). Further, the extinction of bees, important pollinators, for example, has been linked to the end of human life, hence showing the importance of making the connection between food and nutrition security and wildlife conservation.

To ensure intentional linkage between food security and wildlife conservation, therefore, the policy development for food security at a national level should be undertaken as a multisectoral activity that should encompass, but not limited to, the agricultural, forestry, wildlife, environment, and trade sectors (IUCN, 2013). Without this linkage, policy enforcements related to wildlife conservation would instead be a significant contributor to food and nutrition insecurity.

Loss of forest cover, for example, has led to flooding, seasonality of rivers, loss of habitat for important insect pollinators, and reduced access to wild and medicinal plants, which result in reduced food and nutrition security of rural communities. The loss of biodiversity due to human activities results in reduced agricultural productivity and fuels the vicious cycle where communities living near forests continue encroaching into the forest. Actions to conserve wildlife should be deliberate in enhancing food and nutrition security to populations depending on the natural resources, whether near or further in geographical distance.

Food and nutrition security is also jeopardized by increased postharvest losses at the farm level and also along the food value chain. Postharvest handling of farm produce highly influences the quantity and quality of food available to the rural and urban populations. The quality and quantity of food available depend on postharvest handling of food at the point of production and as food moves along the value chain. Poor handling of food leads to food wastage and also diseases which adversely affects human health.

9.2.4.1 *Postharvest losses and food safety*

There is a lot of food lost through poor postharvest handling. Postharvest losses contribute significantly to food and nutrition insecurity along the food supply chain. These necessitate rural households to supplement their food needs by collecting veldt products. For proper human health, there is a need for adequate consumption of energy, protein, vitamins, minerals, dietary fiber, and antioxidants giving foods, which are plant and animal-based products. Consumption of fruits and vegetables on a regular basis has been associated with the reduction of lifestyle diseases such as cancer, heart disease, stroke, and diabetes (Kader, 2005; Emongor, 2010). Some of these products are collected from natural forests and from wildlife areas. At the global level, food production has significantly increased in developed countries; however, in the developing countries many people do not have access to adequate food supplies due to frequent droughts, floods, and war (Kader, 2013; Emongor, 2014). These inadequacies in food availability and affordability have been acerbated by postharvest losses at all levels of the food value chain. Access of communities to wild fruits and vegetables from conservation areas contributes immensely to the improved health of farm households but this can be curtailed by laws and policies that aim to keep people out of the conservation areas.

A postharvest food loss is any change in the quantity or quality that prevents or alters its intended use or decreases its value. Postharvest food losses tend to be highest in countries with the greatest need for food (Emongor, 2014). Postharvest food losses vary in magnitude along the food value chain (Emongor, 2010, 2014). Estimates of the postharvest food losses for grains have been estimated at 25% (Kader, 2005; FAO, 2008). Primary and secondary causes of food deterioration vary across countries and cultures. The different causes of food spoilage influence the availability and affordability of food, hence contributing to food and nutrition insecurity. Postharvest losses vary in magnitude across and within commodities, production regions, and growing seasons. Reduction in postharvest food losses would be of importance to both farmers and consumers. These will lead to conservation of the environment as less land would be required for production; hence there is reduction in encroachment on wildlife habitats leading to conservation of biodiversity and reduction in wildlife–human conflicts.

The postharvest physiology of a food product is influenced by the product itself, especially its perishability, the intended use of the product, the storage environment, handling conditions, the relative abundance of the product at the time, the culture of the society, and socioeconomic factors. To reduce postharvest food losses, all stakeholders in the food value chain such as farmers, traders, processors, and end users must understand the primary and secondary causes involved in food deterioration and spoilage. The use of postharvest technologies such as refrigeration, controlled atmosphere storage, and modified atmosphere packaging that delay senescence, ripening, deterioration and maintaining the best possible food quality are recommended (Emongor, 2014). Reduction of postharvest food losses can increase food availability, decrease the land area needed for production, therefore leading to reduced encroachment on land allocated to wildlife and prevent HWC. Minimizing postharvest food losses is more sustainable than increasing production to compensate for food loss, resulting from poor postharvest handling of food from production to consumption. To achieve this, more funding toward agricultural research, extension, and postharvest handling programs is required in developing countries.

9.2.4.2 *Food safety factors*

Food safety is threatened by several factors such as glycoalkaloids, toxins of fungal (aflatoxin, patulin) and bacterial (*Salmonella*, *Listeria*, and *Escherichia coli*) origin, viruses such as Norovirus, parasites (trematodes and prions), heavy metals, environmental pollutants, and pesticide residues (Emongor, 2010). Food contamination can occur at any point of the food value chain from the farm to fork (harvesting or slaughtering, storage, processing, distribution, preparation, handling, and consumption). Microorganisms release toxic substances to foods leading to food condemnation for human consumption, leading to food insecurity. Consumption of foods contaminated with aflatoxin or patulin has been associated with certain forms of cancer in human beings and other animal species (Hendricks, 1994). Food safety is an important aspect of food security and nutrition. WHO (2006) developed five keys to safer food manual, which has been translated into many languages of the world with the goal of promoting safe food handling and educate food handlers and consumers, thereby leading to prevention of foodborne diseases. Microbial contamination of food is ranked top by public health authorities and scientists, whereas many consumers rank pesticide residues as the most important safety concern (Emongor, 2010; Emongor et al., 2010). Generally, horticultural, agronomic, and fodder crops are free of human and enteric pathogens, unless fertilized with sewage effluent or sludge (Emongor, 2009). Organic manures must be completely decomposed before application to horticultural and agronomic crops especially those eaten as salads to avoid the risk of contamination with bacteria (*Salmonella*, *Listeria*, *E. coli*, fecal coliforms), viruses, and other pathogens such as worms (tapeworms, hookworms, roundworms, and threadworms) (Emongor, 2012). In order to achieve and maintain food safety, the focus should be on maintaining high standards of hygiene and sanitation at all levels of the food value chain. Strict adherence to good agricultural practices also helps in minimizing chemical and physical hazards along the food value chain (Emongor, 2012). The health of the workers handling horticultural produce consumed raw is also important in reducing microbial and other pathogen contamination hence increased food security.

9.2.5 Contribution of wildlife to household food and nutrition security

Wildlife contribution to the economies of African countries through tourism and sale of wildlife products has been well documented. For example, in Kenya wildlife and related activities contribute 12% of the gross domestic product (GDP) (the Republic of Kenya, 2018). Results from a study carried out in Ghana, Rwanda, Uganda, and Tanzania showed that geographic location influenced whether rural households could collect wild foods from the wild areas or not. Households located near wildlife sanctuaries collected wild food from forest areas to supplement rural household diets and income. The wild food collected also contributed to dietary diversity (Cooper et al., 2018; Alders and Kock, 2017). In view of the previous discussion, policies formulated to conserve natural resources in these areas may limit access of local communities to the food resources they desperately need if not well thought out. These communities neighboring the game parks, game reserves, and other conservation areas may not be able to access wild food products from these gazetted areas. Limited access by these communities may interfere with access to food, leading to food and nutrition insecurity, and reduced food diversity for these households, which might lead to poor health of men, women, and children who depend on proteins from wild animals and plants.

Apart from food, households in rural regions that border conservation areas also obtain other benefits such as ecosystem services, water, and wild products. For example, communities especially the rural poor who live near-natural forests obtain diversified products and ecosystem services from the forests, which sustain their livelihoods. Among the activities that contribute to the livelihoods of communities, near-natural forests include gathering firewood, preparing charcoal, fishing, hunting, collecting materials for making handicrafts, and accessing nontimber forest products such as medicinal plants, fruits, and rubber, among others. Other products obtained by these households include food products such as mushrooms and honey, medicines, fodder, fibers, fuels and timber for construction, fencing, and furniture (FAO, 2010). These products may be sold or used at household level, leading to improvements in welfare and income of the said households. Therefore lack of efficient management systems and utilization of the natural resources may lead to degradation of these resources and loss of biodiversity, which affect many people far and near regardless of gender, race, age, and level of income. However, the degree of severity of impacts on communities resulting from degraded resources depends on several factors such as the economic status of the household, health, education level, and gender. The effects are even more serious when laws and policies that are intended to safeguard forest areas are unfavorable to women who depend more on forests to get fuel wood, water, and wild foods. This may impact the food security of women and children in developing countries.

9.2.6 Gender, wildlife conservation, food, and nutrition security

Gender, wildlife conservation, food, and nutrition security are intricately linked as food production in developing countries is mainly the responsibility of women and girls, yet, women and girls are among the vulnerable groups due to inequality in resource endowments and labor drudgery at the household level. Results of a number studies, documented evidence, showed that when women have control over key resources and actively participate in related decision-making, the prevalence of child malnutrition at the household level is reduced (Rahman et al., 2015; Allendorf, 2007). In addition, when women participate in the production or marketing of their agricultural produce and keep proceeds from the sales, this tends to increase their incomes and this, in turn, raises their influence in the decision-making process pertaining to the use of income at the household level. This, in turn, leads to improvement in consumption within given socioeconomic and cultural households (Grace et al., 2015; Van den Bold et al., 2015; Ruel and Alderman, 2013). Women and girls are responsible for household chores, farm production, and safeguarding of the environment. Gender is about social attributes and opportunities. It distinguishes the roles and responsibilities done by women, men, boys, and girls within a given society. It is about relationships and decision-making power among the different gender categories. In most societies, women and men normally carry out unique roles and tasks in agricultural production systems. The errands undertaken are gender-specific (O'Sullivan et al., 2014; Quisumbing et al., 2014; Gebreselassie and Haile, 2013; FAO, 2011; Anriquez et al., 2010; AASTD, 2008; World Bank, 2008b). Both men and women depending on a given society or culture have different privileges and tasks regarding different crops, livestock species, and products (Nigussiel et al., 2014; Anriquez et al., 2010; Yisehak, 2008).

In Kenya, agriculture is the mainstay of the economy, providing at least 29% of the GDP and employment for both paid and unpaid workers of about 75% and raw materials for agro-processing or manufacturing. About 80% of the labor force in the agricultural sector in the country is provided by women and girls (RoK, 2009a, 2009b, 2011). This is also true in other developing countries (FAO, 2015; Doss, 2014; Nelson et al., 2012). Women's labor force participating in agriculture in sub-Saharan Africa is recorded to be the highest (Quisumbing and Pandolfelli, 2010). Results of a study on farming in Kenya showed that if women equally accessed farm inputs, education, and experience compared to their male counterparts, the crop yields would increase by 22%, leading to improved food security. However, balance is required so that women are not exposed to dangerous substances such as pesticides, biological agents, and vectors that can negatively impact nutrition (Gajadhar, 2015; Grace et al., 2015; Turner et al., 2012). This is critical because economic or income-generating activities can easily compromise the quality time spent on child care, child, and maternal nutrition (Johnston et al., 2015; Kadiyala et al., 2014). Hence by empowering women, this can lead to increased productivity, improved child health, nutrition, reduced infant mortality, and access to nutritious and diverse diets (Coleman, 2011).

In Kenya, like in any other developing country, loss of biodiversity affects the different gender categories. Although both men and women are affected, women are most affected because of the multiple roles and responsibilities that they play at the household level. These impacts are seen in increased household labor, poverty, and reduced health because gender and environmental issues tend to be linked in various ways. This is seen in women compromising a disproportionate percentage of the poor segment in the world; both men and women using natural resources differently in accomplishing their defined societal or community roles. There is also a differential treatment of women under legal, political, and social regimes that tend to affect women's ability in effectively managing the resources. Hence, gender inequality tends to alter women's access to assets, public goods, and services meant to increase livelihoods. The presence of assets gap within households tends to dictate the unequal distribution of resources among the different family gender categories. The access of women to employment is also constrained because women are also overburdened at the household level (Nyongesa et al., 2016b).

There are also external factors (changes in demographic trends, globalization, economic development, and climate change) that tend to exert additional pressure on communities and more so on women. These factors tend to negatively impact both biodiversity conservation and poverty alleviation efforts. Increased population density is known to affect the natural environment seen in increased deforestation, decreased land or farm sizes, soil erosion, encroaching on wildlife habitats, and pollution (Shandra, 2008). The increased rate of farming reduces the time for land being left fallow, decreases land productivity, and increases reliance on biodiversity resources. This forces farmers to expand their farming activities into marginal lands and encroaching on public property to conduct their farming activities. The available fisheries are also severely fished. An increased number of fishers may tend to use marginal areas or destroy fish nurseries and rearing grounds. Thus all these uncontrolled activities due to population increase are a major cause of biodiversity loss in Kenya. It has led to the opening up of forest lands, increased fishing pressure, conversion of mangroves in coastal Kenya, disappearing water sources due to encroachment on the Mau forest, and other impacts to common property resources. This confirms the interlinkage and relationships between poverty, gender, and environmental degradation. It also confirms that as poverty and inequality increase, health decreases and biodiversity loss increases. Unequal economic growth tends to increase poverty within certain population segments especially among women. This increases both poverty and negative environmental impacts. Empowerment of women (Galiè et al., 2017) can thus serve as an approach to improving household food and nutrition security (Verhart et al., 2015; Sraboni et al., 2014).

Studies on empowerment and nutrition have shown that if women earned an income in the household, child and household nutrition would more likely improve compared to when the income was earned by men (UNCF, 2011; Smith et al., 2003). This is especially critical at this time when agricultural systems are becoming increasingly vulnerable to climate change, variability, and globalization and degradation of the natural resource base. There is also a persistent increase in prices of inputs such as seeds, chemicals, and fertilizers. Women are disproportionately impacted by climate change (Nyongesa et al., 2017). These impacts can be in the form of natural disasters, food security, water security, economic security, and energy security. A better understanding of where such inequities lie could help find ways in which research could help in overcoming barriers to resilient household food and nutrition security in light of wildlife conservation. Gender targeted research using approaches such as Action Learning for Sustainability (Mayoux and Mackie, 2009; Vogel, 2012) and Pro-WEAI tool (Martinez, 2017; Heckert and Kim, 2016; Doss and Caitlin, 2014) could be effectively used in understanding the interlinkages between gender, wildlife conservation and food, and nutrition security.

9.3 Food and nutrition security and conservation: Kenyan case studies

9.3.1 Introduction

A lot of effort has been made toward wildlife conservation in Kenya in the colonial era as well as after independence up to the current period. These efforts have borne fruit in some areas, whereas in others not much has been achieved. In the following section, case studies from Kenya are given in an attempt to show the link between wild conservation and its effects on food and nutrition security.

9.3.1.1 Contribution of wildlife to the Kenyan economy

Wildlife is the foundation of the tourism industry in Kenya; therefore wildlife conservation is critical to the Kenyan economy as wildlife tourism is the bedrock of the tourism industry in Kenya. The tourism sector contributes immensely to the Kenyan economy; 12% to the GDP and 19% of the total wage employment (Vernon, 2010). It contributes significantly to the local and national economies (Udoto, 2012). The government of Kenya identifies the tourism industry as one of the growth engines for the national economy (Wanyonyi, 2012).

Forests found in gazetted areas managed by Kenya Wildlife Service (KWS), the so-called water towers are the important starting place for many rivers, which form a source of water for domestic and for agricultural use in Kenya. These include water catchment areas of Mount Kenya, the Aberdares, Mount Elgon, Chyulu Hills, Marsabit, and the Mau Forests complex. For example, Mount Elgon National Park is an important water source of many rivers in East Africa such as Nzoia and Turkwel. This gazetted game park serves as a vital source of water for millions of people in eastern Uganda and western Kenya. These rivers are also catchment areas for major lakes such as Kyoga, Turkana, and Victoria, and eventually for the Nile River. The people who live near obtain forest products such as wood and nonwood products such as medicinal herbs (Udoto, 2012).

Apart from the previous discussion, wildlife also contributes raw materials for industry and game meat, which contribute to the protein intake of households. The government also earns revenue from wildlife-related activities and wildlife tourism, which creates jobs and consequently has a significant downward large demand for food, leading to agricultural development. Given the foregoing, wildlife conservation, food and nutrition security in Kenya are intricately linked.

9.3.2 Kenya wildlife conservation areas (game parks and national game reserves)

Kenya's Wildlife Conservation and Management Act provides for three types of wildlife protected areas, namely, national parks; national reserves; and game sanctuaries. Superintending these protected areas is vested in the KWS. As a state corporation, the KWS was established in 1989 by an Act of Parliament Cap 376. Its mandate is to conserve and manage wildlife and enforce associated laws and regulations. Public forest management falls under the Kenya Forest Service (KFS), a state corporation established under the Forest Act 2005, and the mandate of KFS was increased under the Forest Conservation and Management Act of 2016. The mandate of the KFS is to ensure conservation, protection, and management of all public forests. Therefore KWS and KFS are key institutions in the management and conservation of natural resources in Kenya.

In wildlife management and conservation, the country has 54 national parks and game reserves (Fig. 9.1). Located in the capital city of Kenya, the Nairobi National Park is a national park that has close proximity to the capital. It, therefore, attracts a large number of both local and international visitors earning government revenue. The Nairobi National Park is rich in biodiversity, hosting a variety of Africa's best known wild animals such as giraffes, zebras, ostriches, lions, baboons, cheetahs, and endangered species of black rhinos and white rhinos (MoDP, 2013). Its sustainability is however threatened by the accelerated pace of urbanization and development. Kajiado and Narok counties, located in the Southern border of Kenya, have large tracts of land dedicated to wildlife conservation. The counties boast of a wide range of wild animals, which include wildebeests, gazelles, zebras, warthogs, hyenas, giraffes, elephants, lions, leopards, and elands, in an area surrounded by human settlement. Areas designed for game reserves are Amboseli National Park, which covers a total area of 392 km^2, and Chyulu conservation area in Makueni County covering an area of 445 km^2. These areas fall within the rangelands (MoDP, 2013). These areas support wildlife conservation as well as agricultural activities by communities that dwell in the proximity of the game parks and game reserves and hence support the livelihoods of the people.

9.3.3 Human–wildlife conflicts in Kenya

HWC is the interaction between humans and wildlife, which leads to negative economic and social impacts of communities in Kenya and other parts of the world (FAO, 2014). This is a problem that is experienced in many areas of the world where people and wildlife interact and share limited resources. When humans and wildlife compete for limited resources, a lot of undesirable impacts such as destruction or disruption of human life and livelihoods occur. The conflict involves people and their property on one side and wildlife on the other. It also includes interference of the rights of individuals, groups or community, and wildlife. HWCs may lead to food insecurity as wildlife move into human spaces and destroy crops and livestock. This may impoverish farm households dwelling near wildlife reserves. The types of conflicts include predation, crop destruction, property destruction, and destruction of human life. These have an impact on food and nutrition security of affected households and may lead to increasing poverty in these areas.

As wildlife habitats are lost, there is intensified competition between wildlife and humans, since the wildlife is confined into smaller pockets of suitable habitat. Direct or indirect alteration of the quantity or quality of wildlife habitat as a result of human activities such as agriculture, fishing, cutting trees for timber, infrastructural development including roads and railways and building tourism hotels further compromise wildlife habitats. Other habitat changes may be caused by natural factors

Kenya wildlife service conservation areas

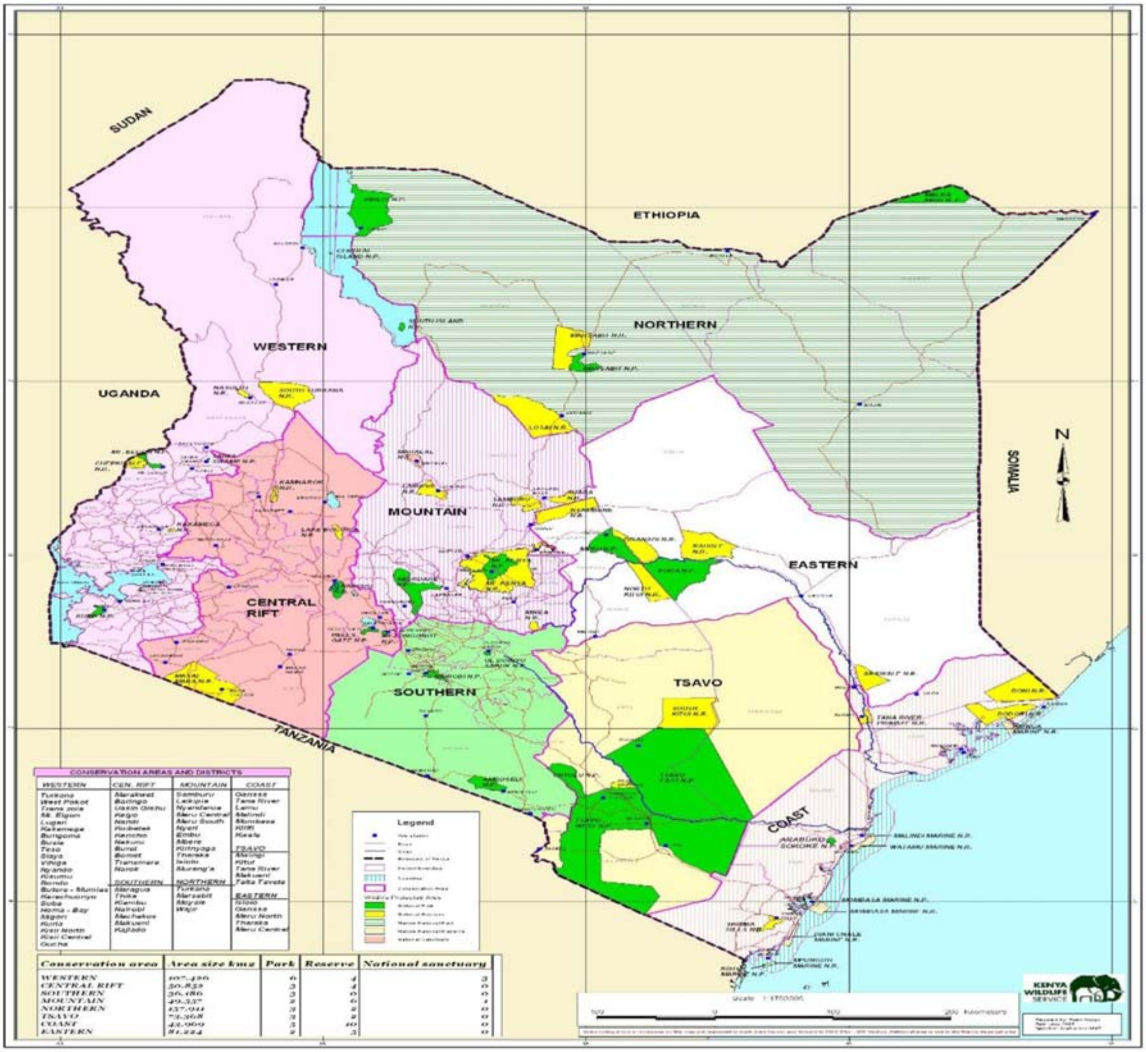

FIGURE 9.1 Map showing wildlife conservation areas in Kenya. *Source: Kenya Wildlife Service (2019).*

such as drought, bush fires, and climatic change. Changes in human attitudes and perceptions toward wildlife and their habitats also play a key role in altering wildlife habitats. For example, some people see wildlife purely as an economic resource that is available for their use without cost implication, leading to the indiscriminate destruction of species such as elephants and rhinos for their valuable tusks and meat, resulting in a reduction of their numbers and in some cases extinction. Landowners, other land users, and some wildlife managers still sometimes deliberately kill wildlife species that they consider to be a

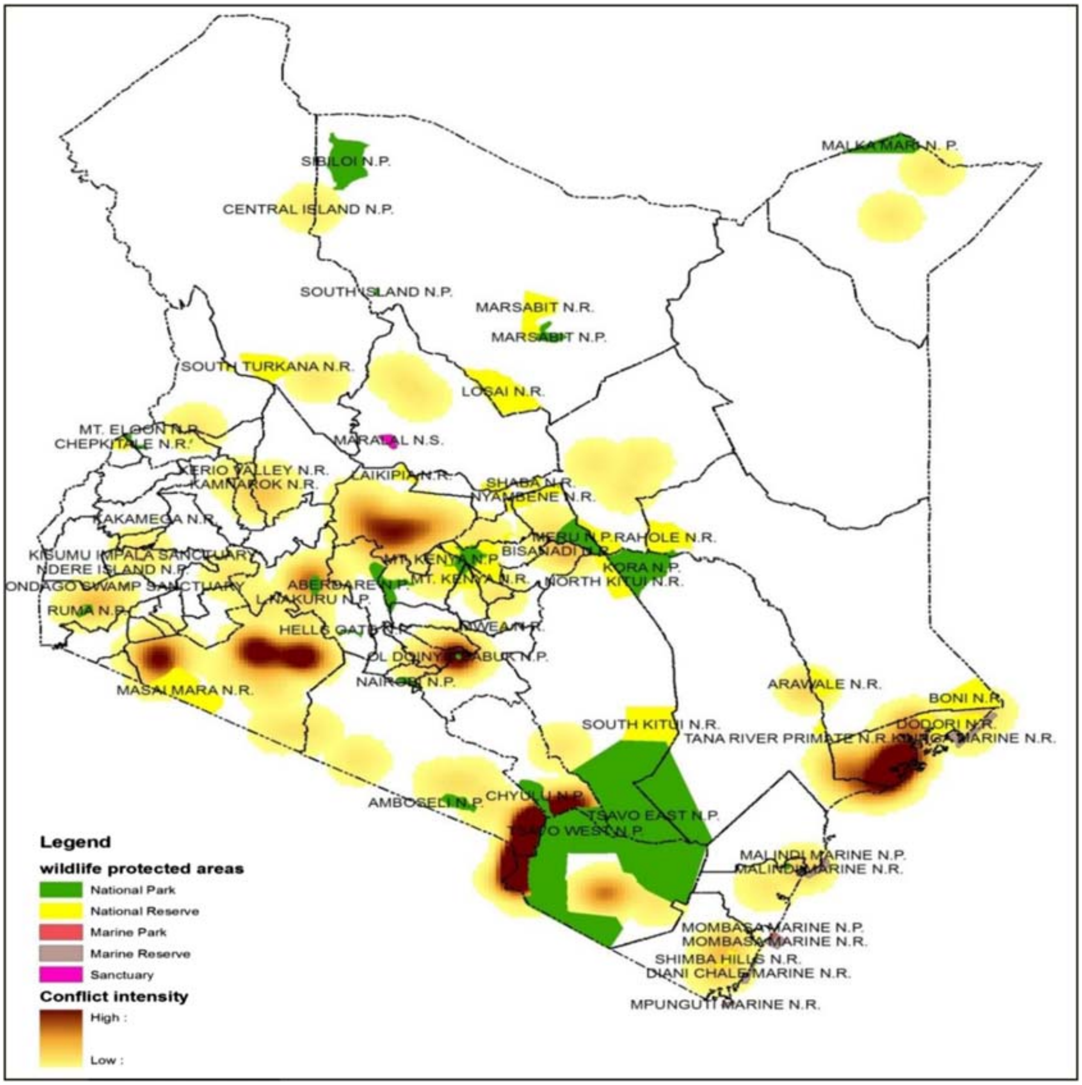

FIGURE 9.2 Human–wildlife conflict hotspots in Kenya. *Source: Kenya Wildlife Service (2019).*

threat. Extermination of large carnivores has been linked to human–lion conflicts as pastoralists retaliate when their livestock is attacked by the animals.

In Kenya, HWCs have been on the increase. In some parts of Kenya, HWC is prevalent and these areas are hot spots as shown in Fig. 9.2. These areas are usually close to wildlife sanctuaries such as game parks and reserves. Areas, where HWC are prevalent, include Laikipia, Transmara, Tsavo East and West, Lamu, Meru, and Amboseli region.

As already alluded, HWCs have been on the rise in Kenya. These trends have been due to land-use modifications and wildlife habitat loss resulting from the increasing human population. This trend has been observed in many areas of Kenya where wildlife and humans live close to each other. In some instances, some wildlife species are on the verge of extinction. As the human population increases, the need for human development increases as well, resulting in increased competition between humans and wildlife for the same resources. The deforestation of forests and other ecosystems for other uses such as agriculture and human settlement lead to declining space for wildlife. As both wildlife and human populations increase, there is an amplified competition for water resources and increased poaching for game meat and trophies by humans, which lead to declining animal species. Migration of people for various reasons such as insecurity or in search of food as a result of natural disasters for example droughts, floods, civil unrest, or war disrupts the production and distribution of food. War and civil unrest destabilize people forcing them to seek shelter in protected areas. The large influx of people in these fragile environments leads to the destruction of natural resources. Frequent droughts and resulting desertification of the land may contribute to food and nutrition insecurity in the regions where these internal migrants have settled.

9.3.3.1 Human–wildlife conflict in the Tsavo conservation area

The Tsavo conservation area (TCA) covers Tsavo East National Park which stretches from south Kitui National reserve in Kitui County to Mkomazi Game Reserve in North-eastern Tanzania, through Taita Taveta county, Tsavo West, and Chyulu National Parks, which stretch from Kibwezi forest in Makueni County, Kajiado county all the way to Kenya–Tanzania border. These areas form natural boundaries that limit the distribution of elephants and other wildlife species. With an area of 40,000 km^2, the ecosystem hosts the largest wildlife populations in Kenya. Tsavo East and West National Parks cover approximately 22,000 km^2. The remaining area is occupied by private ranches, wildlife sanctuaries, sisal plantations, farming settlements, and ecotourism enterprises. All these areas have become a hotspot for HWCs. There has been an increasing trend in HWCs in the TCA as shown in Table 9.1. The main impacts of the HWC in the TCA include the destruction of crops, loss of animals, and infection of livestock with zoonotic diseases, which result in loss of income

TABLE 9.1 Trends in human–wildlife conflicts in Tsavo conservation area.

Year	No. of reported cases	Crop damage cases	Livestock death cases
1990	21	9	2
1991	30	22	3
1992	40	29	5
1993	59	52	4
1994	90	72	9
1995	810	570	61
1996	1056	299	45
1997	1234	817	122
1998	725	396	119
1999	990	580	116
2000	1428	931	128
2001	1337	944	88
2002	1759	1305	108
2003	1218	896	63
2004	1458	1018	129
2005	1640	1027	150
2006	1745	741	99
2007	12,860	666	112

Note: crop and livestock deaths do not add to the number of reported cases, in some other cases such as injury and deaths of humans are not detailed.
Compiled from data from KWS.

as farmers have to pay for disease control and treatment of infected animals. There is also loss of grazing resources, loss of water facilities, and farm structures as well as the loss of human life and injuries, which might further jeopardize food production as farmers use their finances to treat those attacked by wildlife. In cases where there is a loss of human lives, the affected households are impoverished. All this impacts the food and nutrition security of communities and threatens wildlife conservation efforts (Makindi et al., 2014).

9.3.3.2 Human–wildlife conflict in Maasai Mara and adjacent group ranches

A study was carried out by KWS to investigate the status of the conflict in four study sites in both wet and dry regions of the Maasai Mara ecosystem. The aim of the study was to identify and validate the best-bet strategies to mitigate HWCs through participatory processes within the Mara ecosystem. This objective was achieved using various methodologies: (1) documenting the status of HWCs associated with resource use in different land-use zones in the Maasai Mara, (2) identifying and documenting the current actions of resolving resource-use-related conflicts, (3) identifying sociocultural loss and gains if any related to HWCs and its implications to peoples livelihoods, (4) documenting existing strategies and mechanisms aimed at managing resource-use-related conflicts, (5) validating best-bet practical solutions to mitigate HWCs, and (6) recommending best policy recommendations to enhance best mitigation strategies for improved livelihoods and human–wildlife coexistence in the Maasai Mara ecosystem.

The study area was in Narok County. The county lies between latitudes 0° 50′ and 1° 50′ South and longitude 35° 28′ and 36° 25′ East. It borders the Republic of Tanzania to the South, Kisii, Migori, Nyamira, and Bomet counties to the West, Nakuru County to the North, and Kajiado County to the East. The county headquarters is at Narok Town. The county covers an area of 17,933.1 km^2 (Narok County Government, 2018). This area forms part of the Maasai Mara savannah ecosystem. The Mara Ecosystem houses an important tourist attraction; the Mara Serengeti Wildebeest migration which is the seventh wonder of the world. This region has been subject to considerable vegetation changes due to change in climate and human activity. The vegetation cover of Mara ecosystem consists of a mixture of forest and woodland with scattered bushes. The Mara ecosystem is rapidly being transformed into cultivated land and other uses. The current land uses in the area include pastoralism, tourism, and agriculture (Narok County Government, 2018; Muchane et al., 2012).

The Maasai Mara National Reserve (MMNR) covers a total of 1368 km^2 and is owned by the Government of Kenya. The game reserve is managed by the Narok County Government. Maasai Mara game reserve is home to a variety of wildlife including wildebeests, gazelles, zebras, warthogs, hyenas, giraffes, elephants, lions, leopards, and elands. There has been an increase in the human population in the region leading to increased encroachment into the reserve, subsequently increased cases of HWC, thus threatening the sustainability of the reserve and the tourism sector at large, and also food and nutrition security of the people (Muchane et al., 2012).

The land within the MMNR comprises natural woodland and grassland, primarily a wildlife tourism restricted area. The reserve is one of the conservation areas in the country and is surrounded by group ranches communally, privately, or individually owned. The private and/or communal owners engage in diverse enterprises, mainly pastoralism, agriculture, and wildlife tourism. However, lack of enforcement of land-use policies for the woodland and grassland areas surrounding the park has resulted in increased human disturbances in the form of overgrazing, firewood collection, and unsustainable smallholder agriculture. The agricultural activities have attracted wildlife from the communal ranches, which spill into the farmlands during the dry season in the search of food.

This has intensified conflict, in a region that was previously characterized by a sustainable and harmonious existence between humans and wildlife. Intensified mechanized production of select commercial monocrops, with heavy external input use, has also altered the biodiversity composition around the MMNR. The biodiversity alteration has led to reduced availability of feed for the wildlife as well as the livestock, seasonality of rivers, and subsequently endangered the sustainability of the reserve and food and nutrition security of the growing population in the area (Muchane et al., 2012). The situation has been exacerbated by socioeconomic and political marginalization, inadequate land tenure policies, insecurity, increase in availability of small arms and light weapons cattle rustling, weakened traditional governance of the pastoral areas management surrounding the MMNR, which in turn make the region vulnerable to climatic variability (less food for humans and less forage for the livestock and wildlife; Okech, 2010).

9.3.3.3 Status of human–wildlife conflicts in mountain conservation areas

Increasing human encroachment on wildlife and forest resources in Kenya's mountain conservation areas has led to a new dimension in the management of these resources. In the 1960s, it centered on local overpopulation of elephants in National Parks, while in the 1970s, 1980s, and 1990s, the main issue was the impact of illegal hunting for ivory on elephant populations. In recent years, conflicts between humans and wildlife have emerged as a primary conservation concern. Although estimates vary, large numbers of elephants, buffaloes, and other wildlife species inhabit the Mt. Kenya ecosystem (Waithaka, 1994). Elephants and other large mammals occur nearly all over the mountain, but the densities vary considerably from place to place. Waithaka (1994) reported that the Aberdares National Park had a high density of elephants that had been blocked from their seasonal traditional migrations through the plains of Laikipia to Mt. Kenya.

Historically, elephants probably moved into and out of Mt. Kenya in all directions. Mountain forests play many vital roles as water towers in the country (Kenya Water Towers Agency, 2018). These water towers provide various benefits to people. The water towers are important in Kenya as they provide critical ecosystem services. The other critical roles played by these water towers include capturing and storing rainfall, maintaining water quality, regulating river flows, and reducing erosion. The water towers are also important sources of wood and other forest products, providing many environmental services including protection against natural hazards, landscapes for tourism, recreation, and absorption of greenhouse gases from the atmosphere. A valuation of the Chyulu and Mau East water towers showed that they are of great value and contribute the following: goods and services (8%), tourism (52%), Carbon sequestration (21%), and other services (19%). Given the above, water towers are very critical to the survival of local communities far and near to these hills. These mountain areas face a number of threats such as encroachment on the gazetted forest areas of the mountains, deforestation whereby the forest cover in these forests has declined by up to 40%, and land degradation (Kenya Water Towers Agency, 2018). All these have an impact on the availability of water in the country. Reduced water availability is a threat to food production and hence food and nutrition insecurity of rural households.

9.3.4 Biodiversity destruction and climate change: Mau ecosystem

Located in the eastern Rift Valley of Kenya is the largest closed-canopy indigenous montane forest in East Africa (Bird Life International, 2013). The forest comprises seven forest blocks, namely, South-West Mau, East Mau, Ol'donyo Purro, Transmara, Maasai Mau, Western Mau, and Southern Mau. Approximately 25% (107,707 ha) of the originally gazetted forest area of 452,007 ha has been converted to settlement and farmland (Republic of Kenya, 2009a, 2009b). Through excision and encroachment, the original gazetted forest land area has continued to decrease (Republic of Kenya, 2009a; NEMA, 2013).

The Mau complex is the single-most critical water catchment in the Rift Valley and western Kenya and a major source of numerous rivers. At least 60% of the water draining into Lake Victoria, for example, has its source from the Mau forest. Lake Nakuru National park, MMNR among others are a primal tourist destination in Kenya, which is sustained by water from the Mau forest (Republic of Kenya, 2009b). The forest is therefore, an important national and continental water catchment. Management and conservation of the Mau Forest complex is a crucial provider of ecological services to the country. These services include regulation of river flow and recharge of groundwater and hence mitigating against floods; water storage; reduction of soil erosion and siltation, enhancing water purification; biodiversity conservation; and regulation of microclimate (Republic of Kenya, 2009b). This position the Mau complex is not only important in supporting the tourism, construction, and energy sectors but also very crucial for agriculture and food and nutrition security of the communities living around it, the nation at large and beyond its boundaries. The wealth of biodiversity it supports, some of the international conservation concerns, and the invaluable goods and services it provides emphasizes the importance of conserving the complex for the sustainability of its resources and food and nutrition security of the country. The forest is a key habitat to Kenya's terrestrial animal species, including bird species and insects, which are pillars to food production including moderation of soil and conditions impacting both the tea and coffee industry. Unlike other sectors where water is a vital input, water is an output from the forest.

Despite its importance, the water tower has been highly exploited and continues to be degraded at an alarming rate, threatening the food and nutrition security of many households in the country. This trend is as a result of inadequate institutional mechanisms, policies, and long-term strategic actions to conserve the forest's complex (Republic of Kenya, 2019). The degazettement of portions of the forest enhanced continuous widespread encroachment and ecosystem destruction through settlements, crop cultivation, grazing, illegal logging, and charcoal burning, disrupting the forest's role of being major water storage and output channel to outlying areas. The establishment of large exotic plantations by the government led to a loss of biodiversity by having the monoculture tree species replace the wealth of indigenous forest that has been the identity of the complex (NEMA, 2013). Kenya's economic growth rate is highly dependent on the agricultural growth rate, therefore any reduction in agricultural GDP growth leads to a decline in the economic growth of the country. Increased population growth rate and low access to production resources such as land have resulted in an increased number of local poor people who depend on forest resources. The governments' investment in ecosystem protection has not been increasing, resulting in poor management of natural resources, increasing Kenya's vulnerability to extreme environmental events primarily floods and droughts. The climate change-related environmental events have had a significant influence on Kenya's economic performance as well as on the food and nutrition security of many rural households.

The key drivers of the Mau ecosystem degradation are increased poverty and greed, high population growth, government institutional failure, political failure, and changes in economic policies. Devastating effects of the degradation and the resultant increased cost to the government caused by the degradation have contributed to increased efforts to restore the "water tower." The government has constituted a team to revert the situation by managing the indigenous forests including Mau forest for water and soil conservation, provision of forest goods, and services for biodiversity conservation (Republic of Kenya, 2019). This has started by the eviction of illegal settlers. Removal of illegal squatters from Mau forest is an emotive and political issue as many of the people being removed claim that they do not have alternative land to move to. This obviously impacts the food and nutrition security of these households. The local NGOs are supporting government efforts by enhancing transparency in project operations, accessing required information, strengthening capacity for law enforcement, and engaging local communities, schools, and other partners.

9.3.5 Impacts of human–wildlife conflicts on food and nutrition security in wildlife areas in Kenya

There are various HWCs with varied impacts on sustained availability of desired food in the right amounts and quality experienced in wildlife conservation areas and counties where wildlife and the population interact (Mukeka et al., 2019). HWCs have manifested in various ways in different parts of the country with varying effects. These include the following.

9.3.5.1 Predation

Samburu County has a large and growing population of settled and semisedentary pastoralist communities living on group ranches. Livestock husbandry is the main livelihood and due to the presence of many predators ranging from lions, cheetahs, leopards, hyenas, and wild dogs, predation is very high. The domestic animals are owned by the local people; hence a conflict against their livestock is a conflict against their wealth and food security. As a result, the communities attack and kill the wild animals such as lions, leopards, and spotted hyenas as retaliatory measure (Kissui, 2008). The number and type of domestic animals killed by wildlife depend on the species, seasons (time of the year), and availability of natural prey (alternative wildlife that the predator can feed on, other than the domestic animals). Hyenas, leopards, and wild dogs are known to kill sheep and goats, whereas lions tend to kill cattle. Therefore increased predation results in the destruction of both livestock and wildlife and subsequently impoverishment of the farming communities reducing food availability. This makes them more vulnerable and reliant on food aid to survive, and increased poverty among such pastoral communities that depend on livestock for their food and nutrition security.

9.3.5.2 Crop destruction

Human agricultural activities are spreading rapidly leading to the destruction of natural habitats, alteration of rangeland landscapes, and increased crop raiding by wildlife, an important cause of farmers–wildlife conflict the world over. In Africa specifically, there is a high dependence on the farm for survival by a large proportion of the human population. As humans encroach more into the natural habitats of wildlife, there is an increased conflict between people and the wildlife, and especially the larger herbivores that can often raid farms in search of forage (FAO, 2009). The crop-raiding incidences and regularity are dependent on a number of factors including vicinity of the farm from the protected area, type of food crops and preference for the crop, human activity at the time on the farm, and the time of maturation of the food crops compared to the availability of the wild animals' natural forage. However, wildlife has been known to prefer certain domestic crops such as bananas and sugar cane for elephants, such that when these are available in close proximity, they tend to raid the crops irrespective of the presence of other natural forage. Crop destruction leads to food insecurity in the affected households.

9.3.5.3 Property destruction

Property destruction is another form of conflict where wildlife destroys peoples' properties such as fences, water pans, dams, water pipes, and other types of properties. The occupation of areas that were previously dispersal wildlife areas by the ever-increasing human populations and the further subdivisions of these areas through the use of fences reduces the area available for wildlife activities. The communities regard agricultural activities as being more profitable and beneficial, leading to incompatible changes to land use and consequently, the wildlife destroy the erected fences and other property. The big animals such as the elephants, elands, and zebras are the animals causing the greatest HWC, in turn jeopardizing the wildlife conservation efforts as well as food security of the communities. For sustainability, there is a need for joint efforts in minimizing the conflict and establishing conservation projects that benefit both the communities and wildlife.

9.3.5.4 Effect of conflict on humans

Human beings have remained the most emotive and vulnerable casualties of HWC. Reports of human deaths, injuries, and threats are common. Wildlife often strays into the footpaths where humans use and potentially cause physical injury or hinder them from undertaking their daily errands. Incidences of wildlife preventing students from going to school and those going to the market centers are common. Buffaloes, elephants, and lions are the major threats, and the majority of conflicts are along the roads or in watering points.

9.3.6 Mitigation of human–wildlife conflict for improved food and nutrition security in the conservation areas

Some effort has been done to resolve the issues of HWC in conservation areas to prevent loss of livelihoods for humans and also to avoid loss of wildlife, both wild animals and wild plant species. Some of the mitigation measures are undertaken by KWS include the following.

9.3.6.1 Electric fencing

Traditional methods devised by communities for deterring crop-raiding elephants such as the use of fires, brush fences, and loud noises have generally been unsuccessful (Ndlovu et al., 2016) requiring other methods to be used such as electric fencing. The use of electric fences and other barriers to prevent the movement of elephants into arable land are becoming increasingly vital conservation tools. For example, electric fences are extensively used as conservation tools in Kenya (Thouless and Sakwa, 1995). In 2005 the total length of the existing electric fence in wildlife protected areas in Kenya was 1080 km, and it has increased substantially since then. Large fenced areas include Shimba Hills, Kimana, central Laikipia, parts of Mount Kenya forest, Meru, and Tsavo East. The completed Aberdare fence is the longest game fence in Kenya, extending more than 400 km. Unfortunately, not all electric fences projects have been successful in deterring animals in raiding farms. Due to the ineffectiveness of electric fencing, some have been so ineffective that they have been abandoned, while others have reduced conflicts, but failed to eliminate the problem of crop raiding (Waithaka, 1994). Despite the large sums of money invested in capital and recurrent costs of fencing, there has been a very little formal documentation of the success or failure of these fences, or of the impact of the fences on the protected biological resources and the socioeconomic implications on the communities living in the adjacent farms.

9.3.6.2 Formation of community conservancies

Formation of community conservancies in wildlife areas was aimed at addressing HWC and at the same time have the local communities derive some income from wildlife. For example in Samburu County, the following conservancies were formed: Namunyak, Meibae, Sera, Kalama, West Gate, Nkoteiya, Ltungani, Malaso, Angata Nanyukie/Morijo, Kalamudang, Mt. Nyiro, Elbarta, Ndoto, Kirisia, Sera Rhino sanctuary, Reteti elephant rescue center, and Maralal Game sanctuary. The conservancies have staff (community scouts) most of whom have been trained at KWS Law enforcement Academy whose duties include HWC resolutions as well as ensuring the security of wildlife in those areas.

9.3.6.3 Formation of response teams

KWS has formed several outposts in various hotspot counties to respond to HWCs whenever and wherever they arise. For example, in Samburu County, outposts have been formed in Maralal town, which is the headquarters, and others are Wamba, Suguta, Baawa, Ltakweny, South Horr, and Serolipi, each having staff ranging from two to four, tasked with responding to HWC issues. Their activities include scaring of the animal away from human settlements/farms, trapping problematic animals especially predators and translocating them away from the conflict areas using traps as shown in Fig. 9.3.

9.4 Imperatives and challenges

The natural resources of Kenya, which includes its wildlife and habitats are critical for the social and economic development of

FIGURE 9.3 An example of a trap that is used in human–wildlife conflict resolution. *Source: Kenya Wildlife Service (KWS) (2019).*

the country. These resources are critical for the economic development of the country as they are important for the development of the tourism industry that attracts millions of tourists to the country annually. The tourism industry, which in turn, creates employment for thousands of Kenyans as well as spillover effects such as increased demand for food, which drives the growth of the agricultural sector. The protected areas support wildlife (both plants and animals) biodiversity, which provides ecosystem services for the people such as water, wild foods, and tourism sites, which are very important for food and nutrition security as well as sustainable development of the nation. The proportion of wildlife outside protected areas in the country constitutes 65%. Kenya has the third largest population of rhinos in the world in 2017. The country's 35,548 (8.5%) elephants constitute the fourth largest population in Africa after Botswana, Zimbabwe, and Tanzania (Republic of Kenya, 2018). Tourism in the country is one of the biggest foreign exchange earners.

Wildlife management and conservation are therefore a priority if Kenya has to maintain or improve its earnings from the tourism industry as well as providing ecosystem services to the growing human population. Wildlife conservation and management in the country are meant to preserve the ecosystem for esthetic, scientific, and economic purposes (Republic of Kenya, 2012). According to the national wildlife conservation strategy 2030, Kenya has a rich and unique flora and fauna that contribute to the well-being of the Kenyan people by providing a number of ecosystem services as well as economic growth. Therefore the conservation of these resources is necessary even for future generations. The Government of Kenya is committed to the sustainable management of the country's wildlife resources, so as to contribute to the development of the country and enhance the livelihoods of the Kenyan people, for this to happen conservation of natural resources is a prerequisite. There is a need for commitment by all stakeholders (the government, private sector, communities, landowners, and individuals) to safeguard this natural heritage of diverse landscapes and natural resources as the foundation of the country's collective development—both now and in the future. If this is not done, these resources can be lost forever for Kenya and also the world. The concerted efforts must be well directed toward addressing both the threats and also identifying opportunities emanating from wildlife conservation and management in order to achieve sustainable development.

However, there has been an increased loss of habitat as well as wildlife due to a number of factors such as increasing human population pressure, poverty, rapid development in key wildlife areas, and overutilization of natural resources. Further, all these factors weaken the achievement of sustainable development and attainment of food security and nutrition in the country. Therefore there is an urgent need to address these threats and emerging challenges holistically in order to preserve wildlife conservation areas. The country must protect the irreplaceably valuable natural resources on which its sustainable development depends.

Water availability, quality, and quantity have been on the decline further threatening agricultural productivity, food security, and rural livelihoods. Climate change and related impacts have led to the destruction of road infrastructure by frequent and heavy rains and floods, whereas in some cases increased droughts, which threaten both humans and wildlife. High population growth rate leads to rapid urbanization and pressure on land manifesting itself in HWC. This strains the available education and health amenities and increases crime rate due to unemployment, poaching of elephants and rhinos due to their valuable tusks, and mushrooming of informal settlements in urban areas. Encroachment of forested areas has resulted in major HWC in many areas that result in the destruction of farm crops by animals especially elephants. Wildlife in the unprotected areas is a major impediment to the farming communities. The wildlife menace manifests itself in crop damage, death of livestock, loss of human lives, and infliction of physical injuries to people. As a result, many families have been impoverished. The ever-increasing wildlife menace and the resultant destruction of crops and transmission of diseases to livestock discourage agricultural production. The national government must ensure that national park fences are maintained and secured to discourage encroachment by people, and a comprehensive compensation package for damage to crops, property, and human life is given.

9.5 Conclusion

Wildlife conservation and food and nutrition security are in increasing competition due to increased human population and demand for agricultural and development land for settlements. In order to achieve wildlife conservation and food and nutrition security in Kenya and other African countries, a holistic, multidisciplinary, and integrated approach to sustainable agricultural production must be adopted. This will involve developing new and appropriate, innovative, and sustainable production techniques that take wildlife, biodiversity, and environmental into consideration. This will require that all stakeholders involved in agriculture, health, natural resources, education, and infrastructure development should work as a team for sustainable safe food production that is wildlife and environment friendly. Because wildlife conservation and food and nutrition security are intricately linked, the Kenyan government should create and implement appropriate environmental policies with established legal, institutional, and technical frameworks for sustainable management and conservation of wildlife in protected areas.

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CHAPTER

10

Food losses and waste in the context of sustainable food and nutrition security

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10.1 Introduction

Food losses and waste (FLW) indicate a reduction of food, which is destined for human consumption, along the food chain (HLPE, 2014). FLW take place at the time when a food product is suitable for harvesting or it is just harvested up to the consumption stage or when a product is taken off from the supply chain (Gustavsson et al., 2011; HLPE, 2014). FLW is being increasingly recognized as a global issue with impacts on food and nutrition security, as well as on the sustainability of agri-food systems (Pinstrup Andersen et al., 2016). Furthermore, FLW pose problems also for the ethics of wasting food in a world with increasing food insecurity (Ribeiro et al., 2019). Indeed, the amount of food produced at the farm level is much higher than the quantity that is required for human consumption, but food losses from the field to the fork (i.e., final consumers) are very high and aggravate malnutrition (Smil, 2004; Stuart, 2009; Parfitt et al., 2010; Gustavsson et al., 2011; HLPE, 2014; Berjan et al., 2018; Corrado and Sala, 2018). Therefore reducing FLW is broadly seen as an effective measure to reduce the impacts of agricultural production, enhance food security and nutrition, and improve food system efficiency (FAO, 2019a).

A report published by FAO in 2011 (Gustavsson et al., 2011) represented the first comprehensive attempt for the quantification of FLW. It estimated FLW at about a third of the global food production. The report shows that around 68% of FLW take place at the preconsumption stage (i.e., production, handling, processing, distribution). At the consumption stage, waste is about 32% and occurs especially in urban areas.

According to FAO (2013a), the most wasted foods in the world are fruits, vegetables, roots, and tubers. In particular, estimation of global annual FLW is 20% of oilseeds, dairy products, and meat, 30% of cereals, 35% of fish, and 40%–50% of vegetables, roots, and fruits. Focusing on the food supply chain, 40% of FLW take place at the postharvesting/processing stage in the Global South (i.e., developing and

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emerging countries), whereas more than 40% of food losses occur at retail and consumption stages in the Global North (i.e., developed countries). Here consumers throw away every year about 222 million tons, that is, to say almost the same amount of food produced in sub-Saharan Africa (230 million tons) (FAO, 2013a). FAO et al. (2017) also accounted that the energy and protein malnourishment affecting 815 million people in the world could be tackled with less than 1/4 of food wasted in Europe and the United States. In addition, Stenmarck et al. (2016) estimated that the EU's consumers waste 92 kg of food per person per year.

A more recent study by FAO (2019a) explored FLW based on two subindicators related to Target 12.3 of the SDG 12 (responsible consumption and production): the Food Loss Index (FLI), which focuses on preconsumption stages of the food chain, and the Food Waste Index (FWI) that deals with losses at consumption level. Regarding the FLI, the global losses of food produced in 2016 were 13.8%. Moving to the regional contexts, these losses go from 5% to 6% in developed Oceania (Australia, New Zealand) to about a fifth (20%−21%) in developing Central and Southern Asia. The analysis of food groups shows that the highest losses occur in roots and tubers, followed by vegetables and fruits. Unfortunately, for the FWI, the data are not available yet although significant work has been carried out in implementing the methodology.

In general, FLW are measured in terms of food mass (e.g., Gustavsson et al., 2011). However, accounting FLW in this way does not completely take into consideration the nutrition-related aspects, because preservation of food quantity (expressed in food mass) does not mean that the amount of proteins and nutrients (e.g., minerals, vitamins) is also preserved (HLPE, 2014). Moreover, FLW are not easy to measure, because there are different nutritional and quality attributes that change along the supply chain (HLPE, 2014). For instance, the concentration of nutrients in fresh food is highest after harvesting but continuously declines during storage in conditions of inadequate care and handling. Moreover, nutrients are lost during food processing. In addition, large amounts of vitamins are lost when fruits and vegetables are blanched or dried (Capone et al., 2016; Corrado et al., 2019).

In order to advance in the investigation of the nutritional dimension of FLW, recent research focused on estimation of FLW in terms of macro- and micronutrients for several types of food commodities at various food chain stages (e.g., Scherhaufer et al., 2015; Garcia-Herrero et al., 2019a; Khalid et al., 2019). There are also studies dealing with the assessment of the relationship between nutrient losses and the gap between current and recommended dietary intakes (e.g., Spiker et al., 2017), and with the estimation of the number of people who could be properly fed from food wasted (e.g., Garcia-Herrero et al., 2019a). Furthermore, some authors tackled the nutritional value of FLW in schoolchildren (e.g., Sharma et al., 2019) as well as in children with vitamin deficiency in developing countries (e.g., Lee et al., 2015; Paratore et al., 2019). Other relevant researches explored FLW in hospitals (e.g., McCray et al., 2018) and from the unexplored overnutrition perspective (e.g., Franco and Cicatiello, 2018).

This complex frame stresses the paradox that a huge quantity of food is lost or wasted while there are over 800 million people worldwide that are affected by hunger and malnutrition. According to Pinstrup Andersen et al. (2016), this paradox calls for analyzing the relationships between FLW and food and nutrition security and fostering FLW reduction to achieve sustainable food systems (Koester, 2014; Thyberg and Tonjes, 2016; FAO, 2018, 2019a; Lemaire and Limbourg, 2019).

Therefore this chapter aims to analyze the issue of FLW in the context of food security and nutrition. After providing a brief overview of the causes of FLW in Section 10.2, the environmental and economic implications are described in Section 10.3. Then, Section 10.4 provides a picture of FLW in the context of food systems sustainability, whereas Section 10.5 goes beyond food security (cf. calories) and looks at the nutritional value (i.e, in terms of nutrients) of wasted food. Finally, the chapter provides concluding remarks on the importance of reducing FLW to achieve both food and nutrition security and food systems sustainability.

10.2 Causes of food losses and waste

Generally speaking, FLW are influenced by agricultural production patterns, domestic infrastructure, distribution channels, marketing chains, and consumer food-related practices, and also differs between developed and developing countries (Gustavsson et al., 2011; Garrone et al., 2014; El Bilali, 2020). In the developing world, FLW are caused by the lack of suitable or efficient facilities along the food supply chain (harvest, storage, transport, processing) and ineffective, or even inexistent, coordination among the supply chain actors (Aschemann-Witzel et al., 2017). On the other hand, in developed countries, FLW are caused downstream of the food supply chain, that is, at the intersection among retail, food service/catering, and consumers, but also within the households (Parfitt et al., 2010; Canali et al., 2014; Göbel et al., 2015; Aschemann-Witzel et al., 2019). More specifically, the causes of FLW along the food chain are detailed hereafter (Rolle, 2006; Stuart, 2009; Florkowski et al., 2009; HLPE, 2014; van Boxstael et al., 2014; Stancu et al., 2016; FAO, 2019a).

In developing countries, the production and postharvest handling contribute to the greater shares of the total food losses (Aragie et al., 2018). The causes of FLW in poor, low-income countries are largely related to technical and managerial deficiencies in harvesting, cooling (cf. cold chain), and/or storage (Gustavsson et al., 2011). In industrialized regions (e.g., Europe, Industrialized Asia, North America), losses in agricultural production are mainly due to postharvest grading (especially of fruit and vegetables) related to quality standards set by the retailers (Johnson et al., 2018). Food may also be lost because poor farmers sometimes harvest crops too early due to desperate need for cash or food deficiency. Thus food may get wasted if it is unsuitable for consumption (Gillman et al., 2019). Losses in animal production are high in developing regions (Wesana et al., 2018). These losses are due, among others, to animal mortality caused by common diseases (e.g., digestive diseases, pneumonia, parasites) in livestock breeding. Similarly, dairy cow illnesses (e.g., mastitis) decrease milk production (Gustavsson et al., 2011).

Losses caused by inadequate transport and storage are more important in less developed countries (HLPE, 2014). Indeed, poor storage facilities and transport infrastructure are major causes of losses during the postharvest phase in developing countries (Bala et al., 2010). Large amounts of fresh and perishable agro-food products (e.g., fruits, vegetables, meat, and fish) can be lost in hot climates due to inefficient infrastructure for storage, transport, and cooling (Rolle, 2006; Stuart, 2009). Also, insufficient or inadequate packaging can lead to FLW (Olsmats and Wallteg, 2009).

According to the International Institute of Refrigeration (2009), 23% of perishable agro-food products are being lost in the developing regions because of the absence of refrigeration; the highest wastage rates occur in vegetables, fruits, roots and tubers. Regarding the postharvest losses due to poor storage, data show that the losses of cereals range from 8% to 22%, while nearly 100% of horticultural products are lost in some situations (Parfitt et al., 2010; Gustavsson et al., 2011). For perishable agro-food products, temperature management (i.e., cold chain) is a key element in determining the extent of FLW (Badia-Melis et al., 2018; Mercier et al., 2018). Cold chain management often depends on different interventions (e.g., precooling after harvest, climate-controlled storage, refrigeration during transport, and display for selling) that involve actors all along the food chain (Albisu, 2014; HLPE, 2014). According to Gligor et al. (2018), key obstacles to the implementation of cold chain in Vietnam include inadequate skills of professionals; lack of specific measures for the effective control of the quality and safety of agri-food products; high number of intermediaries and fragmentation of the supply chain; unsuitable market and transport infrastructure; lack of well-functioning information systems; high cost for installation and operation of cold chain (especially for smallholders and SMEs); inadequate training and extension activities; lack of public incentives.

FAO (2015a) pointed out that the causes of FLW in the Arab countries (i.e., Near East and North Africa [NENA]) are due to poor agricultural and farming systems, inadequate postharvest practices (e.g., handling, drying, cold storage), and deficient infrastructure. In several NENA countries, most farmers still use traditional methods in grains storage, and insects, rodents and birds are also responsible for losses of cereals (FAO, 2015a). Furthermore, the NENA region has difficulties in improving the capacity of the cold chain because of its hot climate, the lack, and/or the unreliability of the power supply. Moreover, the maintenance and management practices are further key factors affecting the efficiency of the cold chain in this region.

Unsafe food—that does not comply with minimum food safety standards—is wasted as it is not fit for human consumption. A variety of factors can determine food unsafety, including unhygienic handling and storage conditions, inadequate temperature control, naturally occurring toxins, contaminated water as well as improper use of pesticides and veterinary drugs (Gustavsson et al., 2011).

The lack of well-performing, effective, and viable processing facilities is another cause of food loss. In many countries of the Global South, the food processing industry is not able to preserve and process fresh agricultural products due, among others, to product seasonality and high cost of processing facilities, especially when used only during a short year period (Gustavsson et al., 2011). Food is also lost during processing. Lines of food processing perform oftentimes trimming to make sure that the end product is in the proper size and shape. Usually, trimmings are discarded after this phase. Food is also lost during processing because of spoilage or some errors. In fact, end products with damaged packaging or wrong appearance, shape, or weight often end up being discarded although taste or nutritional value is not affected (Swedish Environmental Protection Agency, 2008; Stuart, 2009).

At the retail stage, large amounts of food are discarded because of quality standards (especially private ones) that highlight appearance (i.e., cosmetic specifications). Some agricultural products are excluded at the farm level by supermarkets, which apply rigorous standards regarding size, weight, appearance, and shape (Stuart, 2009; de Hooge et al., 2018). Indeed, food retailers put forward their commitment to reducing food wastage while at the same time they set standards resulting in the large-scale wastage of still edible agri-food products based on rigorous cosmetic specifications (Devin and Richards, 2018). Therefore large portions of harvested food never leave farms (Stuart, 2009).

Inadequate market systems in developing countries cause high food losses. There are few wholesale markets, supermarkets, and retail facilities that provide suitable display and sale environments for agro-food products. Markets (both wholesale and retail ones) in the Global South are oftentimes overcrowded, small, and unsanitary (Kader, 2005). For instance, markets in the NENA region often lack cooling equipment and suitable operation facilities (unloading, storage, ripening, loading) (FAO, 2015b).

Large quantities and a wide range of products displayed in supermarkets lead to food wastage. Consumers, especially in industrialized countries, expect a variety of food types and brands to be available in stores, which increase the likelihood of some of these products reaching their "sell-by" date before being sold, and thus being discarded (Hebrok and Boks, 2017). Moreover, food products that are close to their expiry are often ignored by consumers (Swedish Environmental Protection Agency, 2008; Reynolds et al., 2019).

Food wastage causes in developed countries (i.e., countries with medium/high income) are mainly linked to consumers' behavior (Mondéjar-Jiménez et al., 2016; Gaiani et al., 2018; Porat et al., 2018). Indeed, inadequate purchase planning (e.g., lack of use of shopping list) and confusing "best-before" and "use-by" expiry dates, besides the careless behavior and attitude of consumers, as their high purchasing power and affluence mean that they can afford wasting food, causing large amounts of food wastage in medium/high-income countries (Stefan et al., 2013; Benyam et al., 2018; Philippidis et al., 2019). In specific contexts, such as schools and hospitals, food wastage is caused by several factors. These include poor preparation techniques, perception of the meals (e.g., quality, taste, appearance), large portion sizes due to inadequate public tenders (Byker et al., 2014; Balzaretti et al., 2020; García-Herrero et al., 2019b), hospital procedures, test scheduling, and individual patients' conditions (e.g., reduced appetite, nausea, and pain) (McCray et al., 2018).

Also, the initiative on The Economics of Ecosystems and Biodiversity (TEEB, 2018) pointed out that the disposal is cheaper than the reuse of food in chains of industrialized countries and the proportions of food waste are growing in parallel to the increase of production and consumption. Careless consumer attitude is exacerbated by the abundance of food in developed countries; the amount of available food per capita in both the United States and Europe has increased steadily during the last decades. Many restaurants serve nowadays buffets at fixed prices (i.e., all-you-can-eat buffets), and this may encourage clients to fill their plates with more food than they would actually eat. Principato et al. (2018) argued that the attitude and skills of restaurant owners, the types of menus (e.g., a la carte, du jour, static), and the restaurant size are key factors in determining the amount of food wasted in restaurants. Moreover, retail stores and supermarkets promote "buy one, get one free" bargains and offer large packages. Also, the food industry tends to produce oversized ready-to-eat meals (Stuart, 2009).

Overconsumption is also considered a kind of food wastage (Blair and Sobal, 2006; Searchinger et al., 2013; Alexander et al., 2017; Schmidt and Matthies, 2018). Alexander et al. (2017) found that overeating has the same negative impact as consumer food waste on food system losses. Some scholars also considered consumption of resource-intensive food items instead of equally nutritious, more efficient alternatives as food wastage (Shepon et al., 2018). For instance, Alexander et al. (2017) highlighted that the highest amounts of losses are linked to livestock production, which makes the case for reduced consumption of animal-based foods to combine the health and climate change benefits (Springmann et al., 2016).

10.3 Environmental and economic implications of food wastage

The loss and waste of food are not only a missed opportunity to improve global food and nutrition security, but also represent an unnecessary consumption of environmental resources and generate economic inefficiencies along the food supply chain (Diaz-Ruiz et al., 2019; Morone et al., 2019). When food is wasted, it means that there is no benefit from the use of the soil and its nutrients, and there are corresponding social costs, which lead to unequal distribution of resources and to sparking conflicts due to increased scarcity of fertile land (FAO, 2014; Conrad et al., 2018; Soorani and Ahmadvand, 2019).

The environmental implications of FLW involve negative consequences for climate, air, water, and land use for food production (Venkat, 2011; Muth et al., 2019). FLW cause a variety of impacts, such as greenhouse gas (GHG) emissions and improper use of natural resources (e.g., water, land) that, in turn, affect ecosystems and the services they provide to humanity (FAO, 2013c; Lipinski et al., 2013). Indeed, wasting food brings about the loss of life-supporting nutrition, in addition to the decline of resources such as water, land, and energy used in food production, processing, and distribution (Capone et al., 2014; FAO, 2012b,c, 2013b; UNEP, 2012a,b; HLPE, 2014; Priefer et al., 2016).

Muth et al. (2019) provided a comprehensive overview of the environmental implications of FLW, focusing on climate and land use impacts. Regarding the impacts on climate, water, and air, the authors highlighted that the emissions of nitrous oxide (N_2O) associated with FLW have a strong impact on stratospheric ozone depletion. Also, nitrogen oxides (NO_x) react with volatile organic compounds in the atmosphere and produce smog. Chemical species of nitrogen (N) and phosphorus (P) are released in the environment during food production and contribute to eutrophication (Lundqvist et al., 2008; Lundqvist, 2010; Priefer et al., 2016). Also, CO_2 emissions contribute to decreasing the pH of the oceans thus compromising their life (Anthony et al., 2008). In addition, specific food chain stages (e.g., production, distribution) release polluting compounds in the atmosphere, which affect negatively human health (Galford et al., 2020; Global Panel on Agriculture and Food Systems for Nutrition, 2018). According to FAO (2014), worldwide GHG emissions due to food waste are 3.49 Gton of CO_2eq. Food wastage in Europe causes the release of at least 170 Mton of CO_2eq, corresponding to about 1.9 of CO_2eq per ton of wasted food.

In most cases, the causes of biodiversity loss (e.g., overfishing, overhunting, competing for invasive species) have direct impacts on species and on their habitats in terms of limiting the resources by means of land-use change (WWF, 2017; Muth et al., 2019). FAO (2014) estimated that 0.9 million ha of land is necessary to produce food that is wasted globally every year. Furthermore, intensive agriculture causes soil degradation that affects the soil's quality, structure, erosion as well as nutrient availability (Wirsenius et al., 2010; Priefer et al., 2016; Muth et al., 2019; FAO, 2019a).

The economic implications of FLW are less explored than the environmental impacts. Basically, they affect both farmers and consumers. The main critical points of the supply chain determining the negative economic effects of FLW are harvest, storage and consumption (Gustavsson et al., 2011). Food wastage accounts for approximately 680 billion USD in the Global North and about 310 billion USD in the developing world (FAO, 2013b). As Gustavsson et al. (2011) highlighted, avoidable FLW have negative impacts on farmers' and consumers' income. In fact, FLW represent an unprofitable investment that decreases farmers' incomes, due to lower marketable yield not followed by a reduction of production inputs (e.g., fertilizers, plant protection products, fuel, workforce, etc.) in terms of quantity and costs (Gustavsson et al., 2011). This directly affects consumers' expenses especially in less developed economies, where a lower amount of food on the market raises the selling price and decreases the purchasing power of consumers (Lipinski et al., 2013; Muriana, 2017). Consumers are seen as the most important factor in the management of the economic implications of FLW (Venkat, 2011; Secondi et al., 2015; Roodhuyzen et al., 2017). In fact, a larger food supply, thanks to food losses reduction at the production stage—without appropriate changes in demand/consumption—can still raise to economic burden

(Rutten, 2013a; Schanes et al., 2018). Furthermore, according to Pineda Revilla and Salet (2018), food rituals (cf. social interaction, conviviality, culinary activities) help to strengthen the significance that households relate to food, thus decreasing the amount of household food waste and, consequently, saving money. In addition, the improved consumers' access to food at even lower prices, especially in developed countries, may simply lead to increasing food wastage (Capone et al., 2016; Stöckli et al., 2018). At the same time, other consumers would continue to waste food if appropriate actions are not be taken (Godfray et al., 2010; Rutten, 2013a; Reynolds et al., 2019). Consequently, it is nowadays clear that reducing food wastage in the critical points of the food supply chain can decrease food prices and benefit consumers (Muriana, 2017; Roodhuyzen et al, 2017). At the same time, this reduction can also raise consumers' spending from savings on previously wasted food at the household level and improve producers' revenues (Rutten, 2013b; Thyberg and Tonjes, 2016).

10.4 Food losses and waste, food systems sustainability, and sustainable development

The nonsustainability of food systems is the main driver of malnutrition and food insecurity. In order to ensure food and nutrition security, all components of the agri-food systems must be sustainable, efficient, and resilient (HLPE, 2014). Therefore FLW are also recognized as a barrier to move toward more sustainable agri-food systems (Foley et al., 2011; FAO, 2019b; Kasza et al., 2019).

At Rio + 20 (UN Conference on Sustainable Development of 2012), the "10-Year Framework of Programs on Sustainable Consumption and Production Patterns" (10YFP) was adopted (United Nations, 2014). This served to highlight once more that effective, deep changes in societal production and consumption are crucial in achieving global sustainable development (United Nations, 2002). The 10YFP represents a global action framework to shift to sustainable production and consumption models. The goal of 10YFP (cf. One Planet Network) is to create, replicate, and scale up sustainable consumption and production models at all levels (regional, national, local) (United Nations, 2014). FLW reduction was proposed as one of the objectives in the preliminary proposal for including a new Sustainable Food Systems Program in the 10YFP. As part of Step 1 of the 10YFP process, a public consultation was held in June–July 2014, gathering inputs to contribute to the development of the Sustainable Food Systems Program (SFSP). FLW were identified by 12% of the participants to the public consultation as one of the top 10 key issues the SFSP should focus on, to bring the most "value added" in accelerating the shift toward sustainable food systems (Lomax, 2014).

Also in 2012 the signatories of "The future we want" declaration (United Nations, 2012) started to work on the definition of a post-2015 United Nations development agenda (United Nations, 2015) in the response of both current and future global challenges. On the backdrop of all these challenges, all the alternatives to ensure sufficient food for the future population must also be achieved through the reduction of FLW (Capone et al., 2016). In the debate and negotiations on the post-2015 agenda, the implementation of indicators to measure the transition toward sustainable food systems becomes a pressing and important challenge (Lemaire and Limbourg, 2019). In fact, these indicators had to meet both political pathways and development strategies, and they had to be economically, environmentally, and socially sound without changing the meaning and principles of sovereignty (Voituriez, 2013). Therefore as Hanson (2013) suggested, the Open Working Group on Sustainable Development Goals (SDGs) proposed SDG 12 (responsible consumption and production) with the target 12.3 for the reduction of FLW (Brun and Agamile, 2014; United Nations, 2015). This target has as a goal to halve per capita food waste, both at the retail and consumer levels, and to significantly decrease losses along agri-food supply chains. In particular, two subindicators were set up within the target 12.3 to measure FLW. The FLI (subindicator 12.3.1.a) quantifies food losses along the food chain excluding the retail level. It measures the percentage variation of losses regarding a group of 10 main food commodities by country and with respect to a reference period (cf. base period). The FWI (subindicator 12.3.1.b) measures the tons of wasted food per capita, considering a mixed stream of products from processing through to consumption (United Nations, 2015; FAO, 2019a).

FAO (2019a) identified the wider connections of SDG 12 and target 12.3 (FLW reduction) with other SDGs related to the food system (Fig. 10.1) by taking into account the expected impacts on business and household costs, food security and nutrition, natural resources, and the environment. Specifically, Fig. 10.1 shows that SDG 12 and target 12.3 are strongly linked to the SDG 2 (Zero Hunger; that deals with food security, nutrition, and sustainable agriculture). Furthermore, possible environmental effects are linked to the following goals: SDG 6 (clean water and sanitation); SDG 11 (sustainable cities and communities); SDG 13 (climate action); SDG 14 (life below water); and SDG 15 (life on land). There are also effects on further SDGs, including SDG 1 (no poverty); SDG 8 (decent work and economic growth); and SDG 10 (reduced inequalities) (FAO, 2019a; Lemaire and Limbourg, 2019). Moreover, progress on further SDGs can provide benefits for the reduction of FLW. These SDGs are SDG 5 (gender equality); SDG 7 (affordable and clean energy); SDG 9 (industry, innovation, and infrastructure); and SDG 17 (partnerships for the goals). However, FAO (2019a) highlighted that these connections can vary greatly between and within countries and can also depend on the application of measures for FLW reduction.

In 2015 the European Commission (EC) presented the Action Plan of the European Union on the circular economy (European Commission, 2014, 2015; Busetti, 2019; Hebrok and Heidenstrøm, 2019). This Action plan includes measures for five priority sectors, among which food waste. Thus the following specific actions will be pursued: develop a common methodology and indicators in order to quantify FLW and to obtain in-depth understanding of the problem; set up a platform of stakeholders (including Member States [MS] and agri-food chain actors) to analyze ways for pursuing the SDGs linked to FLW, share good practices, and evaluate progress toward sustainability; investigate relevant EU legal frameworks linked to waste as well as food/feed for facilitating donations (cf. food banks) and utilization of foodstuffs as animal feed; explore options for more efficient use and understanding of food date marking (e.g., the “best before” label). Furthermore, in 2017 the European Parliament approved a resolution concerning the reduction of food waste and the improvement of food safety (European Parliament, 2017). This resolution stressed several needs, including to support a legally binding definition of food waste; to adopt a common methodology to measure FLW; to examine, the possibility of setting up binding reduction targets; to update the list of food currently exempt from “best before” labeling to prevent food waste; and to propose a modification in the Value-Added Tax Directive that would authorize tax exemptions on food donations (European Parliament, 2017).

Furthermore, in May 2018 the European Commission adopted the revised EU legislation, which included explicit measures to allow the EU to get new and reliable data on the levels of FLW (European Commission, 2018; FAO, 2019a). Subsequently, the Commission also adopted a

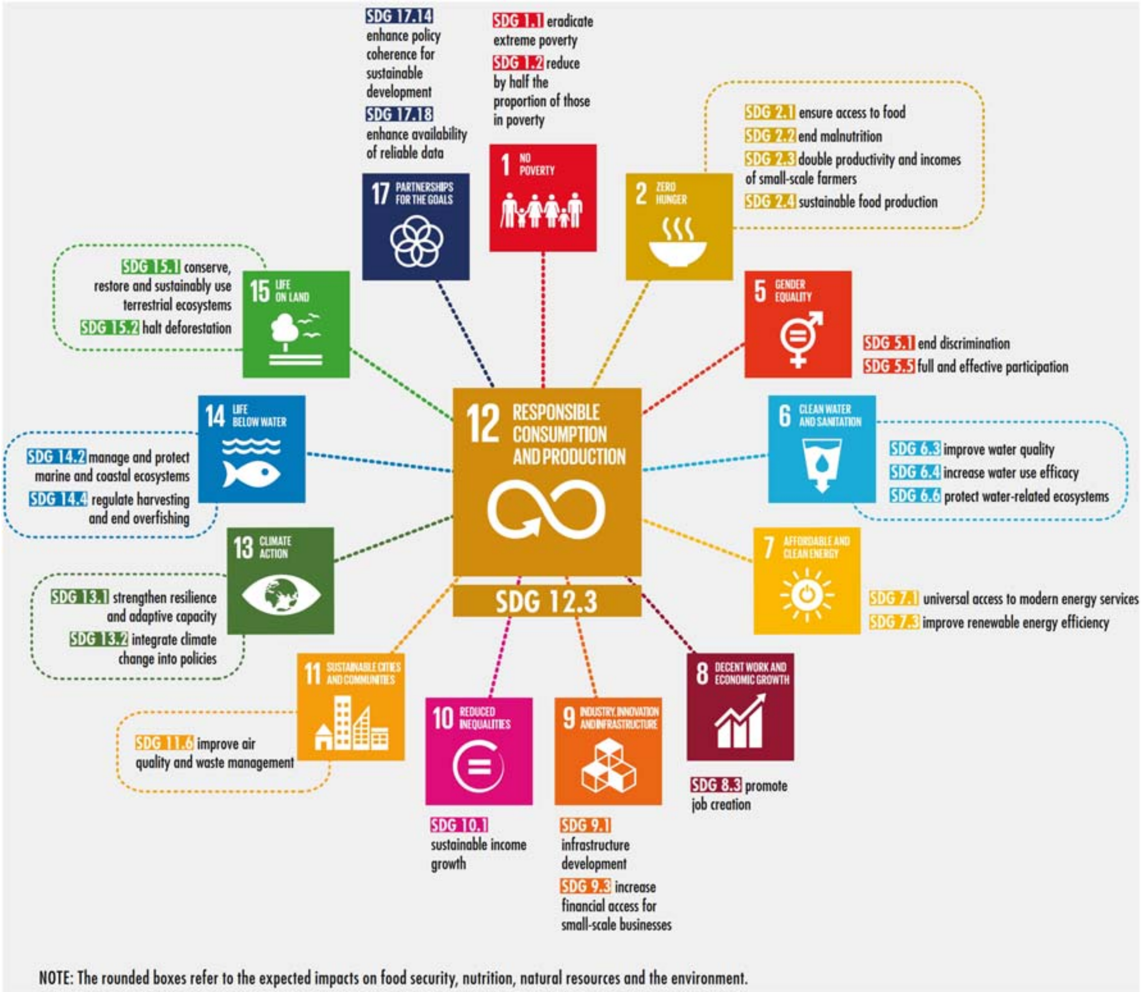

FIGURE 10.1 The connections of SDG 12 and target 12.3 with other SDGs and targets related to the food system. *Source*: Reproduced with permission from FAO, 2019a. The State of Food and Agriculture 2019. Moving Forward on Food Loss and Waste Reduction. Rome. <http://www.fao.org/3/ca6030en/ca6030en.pdf>.
Source: In 2015, the European Commission (EC) presented the Action Plan of the European Union on the circular economy (European Commission, 2014, 2015; Busetti, 2019; Hebrok and Heidenstrøm, 2019).

Delegated Act specifying a common methodology to support MS in quantifying FLW along the agri-food supply chain. This methodology will enable coherent monitoring of FLW levels across the EU (European Commission, 2019a; FAO, 2019a). The MS is asked to deliver separate data for the different supply chain stages (e.g., primary production/agriculture, processing, retail, and food distribution, food services and restaurants, households). Consequently, the obtained data from the MS will provide a valuable contribution to reporting on the subindicators relating to the SDG

Target 12.3 (i.e., FLI and FWI). In addition, the EC's Reflection paper entitled "Toward a sustainable Europe by 2030," highlighted the importance of realizing the Action Plan to reduce food wastage and strengthen food systems sustainability in the EU (European Commission, 2019b; FAO, 2019a).

10.5 Food wastage in the context of food and nutrition security

FLW affect all the four pillars/dimensions of food security that are availability, access, use, and stability (FAO and WHO, 2018; FAO 2019a). Referring to the dimensions of food security, FAO (2019a) pointed out the interactions in terms of decreases or increases in FLW levels (Fig. 10.2). Some of these interactions can directly affect the reduction or increase of FLW, while others can be considered as secondary effects. For example, FLW reduction may increase food availability with a direct decrease in the prices of food. Then, this may encourage farmers/producers to decrease supplies (FAO, 2019a). However, it is important to highlight that Fig. 10.2 shows the potential impacts, while the actual effects will strongly depend on the geographical context under analysis.

FLW are a barrier to achieve food security for millions of people who suffer from undernourishment in the world (FAO, 2012a,b,c; HLPE, 2014). Indeed, around a quarter of food lost/wasted can be sufficient to feed the global hungry population (FAO, 2013b). On the other hand, the global human nutrition scenario displays a huge paradox. Indeed, there is a contrast between 870 million hungry people and the overnutrition of 41 million overweight and obese children under the age of 5, 340 million obese children and adolescents (5−19 years old), and 1.9 billion overweight adults (WHO, 2016). Preserving the nutritional value of food wasted could reduce the unbalance between people who struggle to obtain enough food to survive and those who consume the food beyond individuals' needs (Franco and Cicatiello, 2018). Therefore, many scholars have recently addressed the impacts of FLW on nutrition security.

The Barilla Centre for Food and Nutrition (BCFN, 2012), following the research by Smil (2004), highlighted that globally only 43% of the total food produced (4600 kcal/capita/day) was consumed. An initial reduction of 600 kcal/capita/day was caused by inefficiencies in the upstream of the supply chain (harvest, transport, processing, storage), while the conversion of production (e.g., grains) into feed for livestock caused an additional loss of 1200 kcal per capita and per day. Distribution and retail caused a further loss equal to 800 kcal/capita/day so that the available caloric energy is only about 2000 kcal/capita/day. Also, BCFN (2012) found that in Italy the daily usable caloric content per capita was around 3700 kcal corresponding to one and a half times the daily energy requirement, which generates a leftover of 1700 kcal/capita/day that can cause overeating or wasting.

According to Gustavsson et al. (2011), food waste alone (i.e., excluding food losses) corresponds to the loss of about 10% of the global caloric energy. Furthermore, Kummu et al. (2012) estimated FLW in quantity/mass, applying the FAO's approach (Gustavsson et al., 2011), and found that the 24% of food production lost/wasted corresponds to 3012.5 kJ (720 kcal/capita/day) in Europe. Lipinski et al. (2013) followed the same approach in Europe and estimated that 3129.6 kJ (748 kcal/capita/day) were lost.

Nevertheless, HLPE (2014) pointed out that the use of caloric content to quantify FLW assigns greater importance to energy-dense foods and does not take into account other wasted nutrients. Indeed, this estimation of FLW is not capable to quantify the nutritional losses in terms of micronutrients (e.g., vitamins, zinc, iron) (Chaboud, 2017).

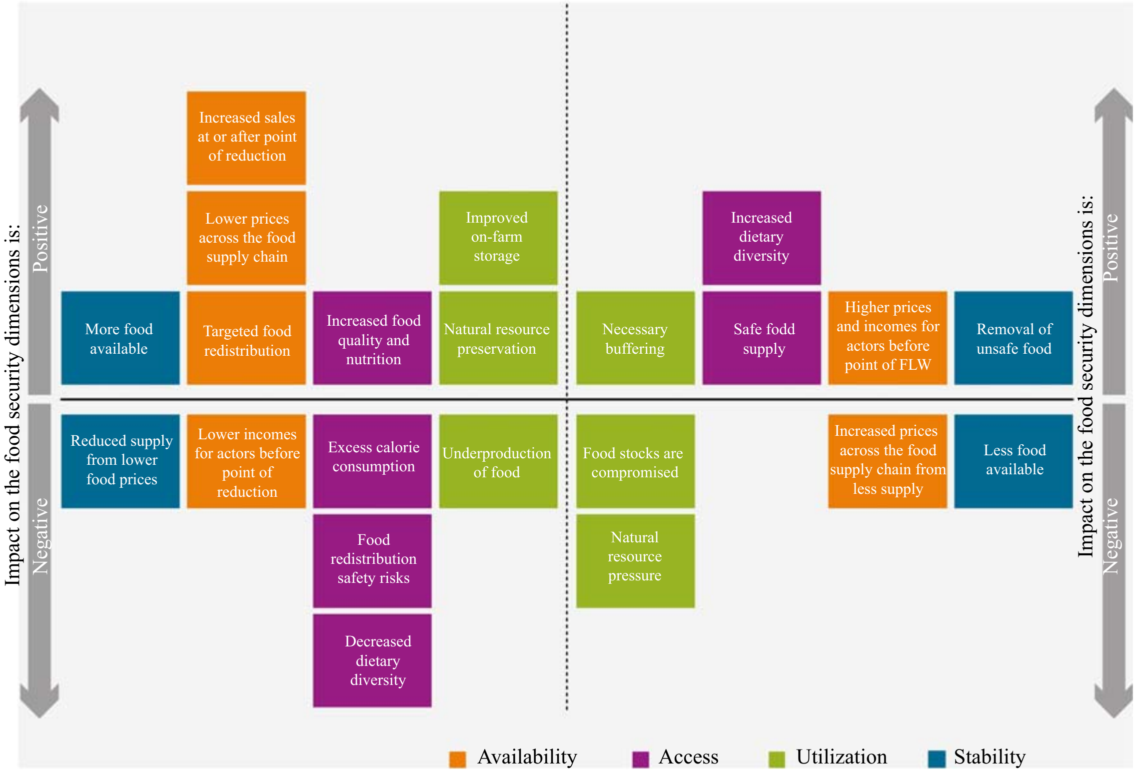

FIGURE 10.2 The potential interactions between FLW and food security dimensions. The left side of Fig. 10.2 represents an FLW reduction scenario (i.e., scenario A), while the right side shows a condition where FLW increases (i.e., scenario B). The *arrows* indicate the potential positive or negative effects of change (decrease or increase) in FLW, with respect to each dimension of food security. *Source: Reproduced with permission from FAO, 2019a. The State of Food and Agriculture 2019. Moving Forward on Food Loss and Waste Reduction. Rome. <http://www.fao.org/3/ca6030en/ca6030en.pdf>.*

By contrast, recent studies aimed to investigate in depth the nutritional dimension of FLW for various food commodities along the food supply chain. Serafini et al. (2015) investigated the losses of vitamins A and C contained in fruits and vegetables within the supply chains of seven regions (Europe; North Africa, West, and Central Asia; sub-Saharan Africa; Industrialized Asia; South and Southeast Asia; North America and Oceania; Latin America). Their results showed that Industrialized Asia had the highest per capita vitamins A and C losses in fruit and vegetables [vitamin A: 784 RE (retinol equivalents)/day and vitamin C: 90 mg/day]. The lowest losses were found in sub-Saharan Africa (vitamin A: 135 RE/day; vitamin C: 26 mg/day). Furthermore, the authors found that globally, harvest, postharvest, and consumption are the stages where there is the highest waste of vitamins, while the lowest wastage occurs at processing. Agricultural production in Industrialized Asia, North America, and Oceania had the highest vitamins A and C waste, respectively (vitamin A: 228 RE/d; vitamin C: 33 mg/d). Industrialized Asia was also the lead region globally with the highest vitamin A waste among fruits and vegetables across the food supply chain, apart from processing. Finally, for vitamins A and C waste in fruit and vegetables at the consumer stage, Industrialized Asia produced the highest waste, while the lowest level was found in sub-Saharan Africa.

Scherhaufer et al. (2015) quantified the losses of vitamins (vitamin A, beta-carotene, vitamin C), dietary fiber, minerals (iron, zinc), *n*-3 fatty acids, amino acids (lysine and methionine) along the food chains of nine food products accounting to 65% of EU's production in 2011 (milk, beef, pork, chicken, apples, potatoes, tomatoes, bread, white fish). They showed that the highest losses of vitamin A in pig meat (about 35,000 kg), beta-carotene in potatoes (about 18,000 kg), vitamin C in potatoes (about 580,000 kg) are at the production stage. Meanwhile, the losses of vitamin C in tomatoes and related-products are highest at consumption (about 430,000 kg). Most of the losses of iron, zinc, fiber, and *n*-3 fatty acids occurred at consumption, particularly in cereal products (about 950 million kg, 310,000 kg, 200,000 kg and 31 million kg, respectively). Lysine and methionine losses were highest in milk (about 70 million kg) and cereals (about 26 million kg), both at the consumption stage. The authors also analyzed the losses of macronutrients and micronutrients in relation to the human nutritional requirements, linking these losses with the recommended daily intake. The estimated nutrient losses in the EU in 2011 caused by food waste corresponded to the recommended daily intake of 90–111 million people for vitamin C, 78–407 million people for retinol (cf. vitamin A), 127–173 million people for dietary fiber, 157–228 million people for iron, and 181–210 million people for zinc.

The research performed by Spiker et al. (2017) concerned the estimation of the nutrition-related value of food waste in the US food supply at the retail and consumer stages, and the investigation of nutrient losses as the difference between recommended and current intakes, thus to estimate the recovery potential. This was done by taking into account 213 food commodities and 27 nutrients at retail and consumption levels. The authors found that the food wasted corresponds to 1217 kcal, 5.9 g dietary fiber, 33 g protein, 880 mg potassium, 286 mg calcium, and 1.7 mg vitamin D per capita per day. Considering dietary fiber, the authors estimated that the food wasted in the United States contained more than 1.8 billion gram dietary fiber. Otherwise, 1.8 billion gram dietary fiber is equal to the full recommended daily intake for dietary fiber for 73.6 million adult women or 48.4 million adult men per day, which is equal to 27% of the US adult population.

Garcia-Herrero et al. (2019a) estimated the nutritional value of FLW in terms of energy, macronutrients (e.g., proteins), fiber, vitamins, and minerals within the supply chains of 13 different agri-food products in Spain. The authors found that FLW accounted to 4251 KJ (1016 kcal/capita/day), 70.7 g/capita/day of proteins, 22 g/capita/day of dietary fiber, 332 mg/capita/day of calcium, 975 μg/capita/day of vitamin A, and 117 mg/capita/day of vitamin C. In particular, most nutrients (about 40%) were lost at production. Consumption (30%) was the second main critical stage of the food supply chain in terms of nutrient losses due to FLW. Nevertheless, the nutritional losses of starch, animal proteins, and vitamins A, D, and B12 were higher than at the production level. The other supply chain stages (postharvest, distribution, processing) accounted for 7%, 8%, and 13% of the nutrient losses, respectively. Moreover, the authors connected the macronutrient and micronutrient losses to the dietary intakes to estimate the number of adult people that can be properly fed from FLW. They found that the nutritional needs of about 80% of the Spanish population can be met, thanks to the nutrients that could be recovered from FLW, although this estimation was carried out by considering the best performance scenario in which all FLW were avoidable and the nutrients were recoverable.

Cooper et al. (2018) estimated the nutritional value of FLW in the United Kingdom for different categories of food at a household level, including fruits and vegetables, bakery products, dairy products, eggs, meat, and fish. Results showed that about 42 daily diets per capita per year were wasted. Considering the single nutrients, the highest losses were related to vitamin B12, vitamin C, and thiamin (respectively 160, 140, and 130 nutrient days per capita per year). Meanwhile, 88, 59, and 53 nutrient days per capita per year were lost when considering proteins, dietary energy, and carbohydrates, respectively. Cooper et al. (2018) also found significant losses in underconsumed nutrients, as follows: calcium in bakery products and dairy/eggs, both at 27%; folate in fresh vegetables (40%) and bakery products (18%); dietary fiber in fresh vegetables and bakery products at 31% and 29%, respectively.

Also, Khalid et al. (2019) focused on FLW at the consumption stage. The authors first quantified the food wasted by type, then they determined the nutritional losses and finally, they examined food waste causes. In particular, the food wasted from 51 households in 24 h was collected, weighed, and classified into different types, including fruits, vegetables, processed food, dairy products, cooked food, and meat (i.e., fish and poultry). Khalid et al. (2019) found that the highest amount of food waste occurred in cooked food (35.02 g/capita/day), while the minimum waste was reported in dairy products (1.98 g/capita/day). The estimation of the nutritional value of household food waste was as follows: energy (54.42 kcal/capita/day), carbohydrates (10.58 g/capita/day), protein (2.61 g/capita/day), lipids (2.21 g/capita/day), fiber (0.75 g/capita/day), calcium (22.49 mg/capita/day), phosphorous (37.11 mg/capita/day), β-carotene (275.2 μg/capita/day), vitamin A (96.83RE/capita/day). This research also showed that food was wasted because it looked bad (50%), meals were mix planned (40%), or cooked improperly (36%). On the contrary, processed food was mainly thrown away because of the lack of awareness of consumers on labeling dates (50%).

McCray et al. (2018) shifted the focus on food waste from households to hospitals and evaluated the nutritional intake of patients in Australia, by comparing a room food service model with a traditional one. The authors found a significant increase in intake in food room service with respect to the traditional one, both in terms of proteins (52 g/day vs 66 g/day) and energy (1306 kcal/day vs 1588 kcal/day), so that food waste was reduced from 29% to 12%.

In a study focusing on the nutritional value of FLW among children, Sharma et al. (2019) explored the preliminary impact of the school-based nutrition program named "Brighter Bites" on decreasing fruits and vegetable waste at school lunches among fourth- and fifth-grade children. The authors argued that the students involved in the program decreased significantly the number of fruits and vegetables wasted at each meal. In particular, there were significant decreases in waste of energy, dietary fiber, vitamins B1, B3, B6, and B12, and total folate with respect to students not involved in the program.

The scientific literature on the nutritional dimension of FLW among children shows that further studies have been carried out. Lee et al. (2015) determined the losses of vitamin A (β-carotene and retinol) in specific food supply chains in Norway and Kenya and estimated the number of children under 5 years old with vitamin A deficiency that could be fed with vitamin A losses. In Norway, the losses of vitamin A were estimated for fruits and vegetables along the food supply chains. Here the annual losses in the supply chains were about 354,824 tons/year (fruit: 227,667 tons/year; vegetables: 127,157 tons/year), leading to about 280.3 kg RE/year vitamin A loss. This amount of vitamin A could meet the needs of about 1807 million vitamin A-deficient children under 5 years old. In Kenya, postharvest losses of vitamin A were evaluated taking into account four food products: banana (including plantain), maize, milk (all animals), and fish (all fish caught on land). Here the annual losses of these food items were 1,835,468 tons/year (bananas: 451,842 tons/year; maize: 879,789 tons/year; milk 462,453 tons/year, and fish: 41,284 tons/year), corresponding to about 338.8 kg RE/year loss of vitamin A; a quantity that could meet the needs of 2.18 million of vitamin A-deficient children under 5 years old.

Paratore et al. (2019) investigated the potential linkages between micronutrient deficiencies and postharvest losses by carrying out an analysis on the scale of micronutrient losses (iron, zinc, vitamins A, and C) in selected food supply chains in sub-Saharan Africa (Cameroon, Kenya) and Asia (India) on vulnerable children under 5 years old. In Kenya, the selected food supply chains were banana (dessert and plantain), maize (flour), and cow's milk. In this country, the highest total losses were found in banana dessert (iron: 7.49 × 109 mg; vitamin C: 2.41 × 1010 mg) and cow's milk (zinc: 1.78 × 109 mg). The reduction of food losses were assumed to meet the requirements of iron and vitamin C (24% and 33%, respectively), and 8% of zinc requirements of all Kenyan children under 5 years old. Moreover, the total percentage of Kenyan children with vitamin A deficiency that could be satisfied in their daily requirements from these food losses would be equal to 21%. In Cameroon, the authors (Paratore et al., 2019) explored food supply chains of cassava (stick and gari meal), red tomato, and potato. Here the greatest losses were found in cassava gari meal (iron: 2.46 × 109 mg meal; zinc: 1.41 × 109 mg) and red tomato (vitamin C: 3.26 × 1010 mg). Losses reduction would be sufficient for satisfying 15% of iron, 12% of zinc, and 83% of vitamin C requirements of all Cameroon's children under 5 years old. In this country, 25% of children with vitamin A deficiency could be satisfied with their daily requirements from food losses. In India, the selected food supply chains were chickpea, rice, buffalo and cow milk, and mango. The highest losses occurred in rice (iron: 8.76 × 109 mg; zinc: 8.64 × 109 mg) and mango (vitamin C: 2.97 × 1010 mg). These losses were assumed to satisfy 2% of children in terms of iron and zinc requirements, and 23% of vitamin C of all children under 5 years old. Furthermore, 21% of children could be satisfied with their daily requirements of vitamin A (Paratore et al., 2019).

Although there are several findings on the nutritional value of FLW, research from the overnutrition point of view is still scarce. However, Franco and Cicatiello (2018) tackled this topic by determining the gap in terms of energy value between the food consumed and the food required by the Italian overweight and obese population. The authors demonstrated that the total calories wasted because of the overnutrition of overweight and obese Italians were approximately 2.67 trillion kcal/year. This value corresponds annually to about 2.28 million tons of food, which is intended as an additional form of food waste at the consumption stage. At the individual level, the average amount of food wasted by each Italian due to overnutrition was about 37.7 kg/person/year.

10.6 Conclusions

The shift toward sustainable food consumption and production can be achieved by addressing both the product supply and the consumptive demand elements through the adoption of smart, adequate, and efficient food consumption and production patterns. The reduction of FLW is considered a concrete strategy since FLW impact the sustainability of the food systems. Indeed, FLW exacerbate the inefficiency of the food chain, thus contributing to food and nutrition insecurity. Moreover, FLW cause unnecessary consumption of resources (including land, water, and energy), produces GHG emissions, and also creates an economic burden and social costs.

Therefore, the reduction of FLW is essential to enhance the sustainability of the current agri-food systems and achieve food and nutrition security for all. In this sense, scholars are devoting attention to FLW beyond food security and are looking to the nutritional value of food wasted. Several pieces of research have been carried out to better understand a variety of issues related to the nutritional value of FLW. These include, among others, the estimation of FLW in terms of macro- and micronutrients for several types of food commodities along the food chain; the assessment of the amount of nutrient loss as difference between current and recommended intakes; the estimation of total number of adult people who could be properly fed from food wasted. However, further studies are necessary to explore FLW from the perspective of overnutrition and to propose more concrete actions and strategies for tackling these issues.

Furthermore, international public authorities, intergovernmental institutions, and nongovernmental organizations are also addressing this multifaceted problem through valuable policy instruments. Indeed, they play a key role in guiding consumers, social actors, and other stakeholders within the food system toward the reduction of FLW. Thus, specific actions being implemented include the targeted awareness-raising and information campaigns and educational programs to consumers; design of appropriate policies, recommendations and good practices for the main actors of the food systems; and adoption of strategies for the prevention and/or reduction of food wastage in the main critical stages of the food chain, from production to consumption. Nevertheless, further effective actions should be carried out, such as improving awareness among the food supply chain actors; setting up further ad-hoc policies and regulations; increasing incentives to support the supply chain actors in tackling the causes of FLW.

In order to achieve the sustainability of food systems (from environmental, economic, and social points of view) as well as sustainable food and nutrition security, a global commitment to the reduction of FLW is necessary. Thus, it is fundamental to implement a systemic, integrated, and holistic food chain approach that should take into account the actual interactions between FLW and the dimensions of food security, as well as the connections among FLW and the SDGs related to food and nutrition security.

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CHAPTER

11

Dynamics and innovative technologies affecting diets: implications on global food and nutrition security

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11.1 Importance of fatty acids in the diet

11.1.1 General aspects of fatty acids

Fatty acids (FA) are part of cell membranes in the human body, and they exert a plethora of actions.

They are part of the structure of the cells as membrane building blocks which permits the regulation of membrane fluidity. Their ester forms are mainly used for energy storage. Fatty acids are oxidized in the cytoplasm through the mechanism known as beta (β)-oxidation, which converts FA into fatty acyl CoA molecules. The fatty acyl CoA molecules combine to form fatty acylcarnitine in the cytosolic side between both mitochondrial membranes. Then, it is incorporated into the mitochondrial matrix to be back converted into fatty acyl CoA that enters into the beta-oxidation cycle. The molecule suffers a series of cleavages rendering two carbons at a time while generating one

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NADH and one $FADH_2$ molecule per turn. The released acetyl CoA then enters into the tricarboxylic acid cycle where the acetyl group is further oxidized to CO_2, generating new reducing power molecules as occurs with the pyruvate-derived acetyl CoA (reviewed in de Carvalho and Caramujo, 2018).

The FAs that are not catabolized are kept as an energy reservoir in the cells. They will intervene in structural functions and also in the biosynthesis of many diverse bioactive eicosanoids.

The long-chain polyunsaturated fatty acids (LCPUFAs) with more than 18 carbons, that are esterified at the 2-position of the phospholipids in the membranes, are released by the phospholipase A2, and the released PUFAs interact with fatty acid oxygenases (cyclooxygenases and lipoxygenases) and produce lipid hydroperoxides that are stimulating cofactors that go on to form many diverse bioactive eicosanoids (reviewed in Lands, 2015).

For further information, a completed schema of PUFA synthesis, including the biosynthesis of LCPUFA, can be seen in the literature previously published by Nantapo et al. (2015).

11.1.2 Nutritional requirements and international recommendations

11.1.2.1 Lipid classes

Dietary FA can be grouped into these three broad groups: saturated, monounsaturated, and polyunsaturated fatty acids (SFAs, MUFAs, and PUFAs, respectively). This classification is based on the chemical nature of fatty acids, but it is clear that individual fatty acids within these groups have distinct biological properties.

In the western diet, the major SFA is myristic acid (C14:0), palmitic acid (C16:0), and stearic acid (C18:0). Those from milk and coconut oil range from C4:0 to C18:0, whereas MUFA refers to oleic acid (C18:1*n*-9) as the main monounsaturated FA. However, in some populations with high consumption of culinary oils derived from rapeseed and mustard seeds, a major MUFA may be erucic acid (C22:1*n*-9). Concerning PUFA, they include mainly linoleic acid (LA; C18:2*n*-6), a lower proportion of alpha-linolenic acid (ALA; C18:3*n*-3), and depending on seafood consumption, there are low but varied species including arachidonic acid (AA; C20:4 *n*-6), eicosapentaenoic acid (EPA, C22:5 *n*-3), docosapentaenoic acid (DPA, C22:5), and docosahexaenoic acid (DHA, C22:6 *n*-3).

Concerning *trans*-fatty acids, those proceeding from ruminal metabolism and coming mainly from *trans*-vaccenic acid (C18:1 *trans*-11 and *trans*-12) should be distinguished from the synthetic and unhealthy *trans*-fatty acids. The C18:1 *trans*-11 and *trans*-12 are precursors from conjugated linoleic acid or CLAs by the action of the enzyme delta-9 desaturase, giving the biologically active conjugated isomers of the C18:2 FA mainly *cis*-9, *trans*-11, and *cis*-10, *trans*-12 CLA (Palmquist and Jenkins, 2017).

Among LCPUFA, the most important for the human diet are eicosapentaenoic acid (EPA C20:5 *n*-3) and docosahexaenoic acid (DHA C22:6 *n*-3). These products are found mainly in marine sources such as algae, seafood, and fish. They play an important role in the prevention of inflammatory reactions and visual and neural development (especially DHA).

The precursor of these fatty acids is the alpha-linoleic acid (ALA C18:3 *n*-3), mainly found in plant oils, but the conversion in the human body is low, approximately 5%−10% for EPA and less than 5% for DHA (Simopoulos, 2000). Therefore they should be ingested in the diet.

Another LCPUFA is DPA, an intermediate in the production of DHA from EPA, and its contribution to beef lipids is higher than that of EPA and DHA. The functional and nutritional attributes of DPA are largely unknown but some studies showed that DPA appears to be a primary end point for the synthesis of *n*-3 PUFA from ALA as increasing dietary ALA or the direct fatty acid desaturase 2 (FADS2) product, stearidonic acid (18:4*n*-3; SDA), increased tissue levels of eicosapentaenoic acid (20:5*n*-3; EPA) and docosapentaenoic acid (22:5*n*-3; DPA), but not DHA (Gregory et al., 2011).

Other minor but important fatty acids coming from bacterial metabolism are the branched species (BCFA). They are present in around 2% in cows' milk and dairy foods and less in meat products. BCFA act in the membranes, giving a higher fluidity to the phospholipids' phase. Due to their branched nature, they impair the formation of rigid saturated FA structures and reduce the phase-transition temperature of the membrane lipids. This BCFA is rare in human tissues. However, they may play a protective role in skin and gut epithelia. They are primary components of dairy and meat and are absent in chicken, pork, and salmon (Ran-Ressler et al., 2014).

11.1.2.2 Fatty acids and food security

The food security concept requires increased knowledge about minor components in the diet as micronutrients, vitamins, bioactive compounds (carotenoids, flavonoids) together with fatty acids, which are naturally present in food and exert biological effects to improve human health.

There are three classes of food insecurity segments according to FAO report (2019): (1) food-secure populations with adequate access to food quality and quantity; (2) moderate insecurity populations with uncertainness about their ability to find a compromise between food quality and/or quantity; (3) severe food insecurity, with people without access to food passing a day or several without eating.

At the same time, noncommunicable diseases (NCDs) such as obesity, type 2 diabetes, and cancer are growing in all regions, despite food access.

In a global context, food insecurity in low- and middle-income countries may be related to the high price volatility of commodities, which is the main source of their economy. This factor negatively impacts in low and medium households and mainly affects the purchasing capacity for high-quality fresh food and healthy transformed foods.

Nutritional transitions conducted to unhealthy consumption of macro and micronutrients. Modern diets led to the high consumption of unhealthy fats. Indeed, ultra-processed foods possess a high proportion of vegetable oils, which are a source of *n*-6 FA, promoting the rise of the *n*-6/*n*-3 ratio to levels above 15 (Nantapo et al., 2015). Ready-to-eat meals are affordable and convenient for people with seldom time to shop around and prepare plates with fresh or healthy processed ingredients. The situation is worse where people are far from marine food sources and may be reversed using aquaculture as an alternative source of animal protein (Beveridge et al., 2013).

11.1.2.3 Contribution to nutritional security

Simopoulos (2002) indicated that rather than the quantity of FA ingestion, the proportion of *n*-6/*n*-3 should be 4/1 for a healthy diet, being a relationship of one the better nutritional option in terms of disease prevention.

However, modern agriculture implies meat and milk-based on cereal and oil sources, which are rich in *n*-6 PUFA. Then, the food products derived from intensive agricultural practices are usually poor in *n*-3 PUFA.

Also, highly processed food has mainly vegetable oils rich in linoleic acid, being the most consumed *n*-6 FA.

In his paper, Simopoulos (2002) concluded that series 18:2 *n*-6 and 18:3 *n*-3 were not interconvertible and competed for the rate-limiting Δ6-desaturase in the synthesis of LC PUFA.

AA (*n*-6) and EPA (*n*-3) are precursors for the synthesis of eicosanoids. However, eicosanoids from these precursors show opposing properties. An increment of *n*-6 eicosanoids due to dietary intake produces a prothrombotic, proconstrictive, and proinflammatory state.

Several chronic conditions, cardiovascular disease, diabetes, cancer, obesity, autoimmune diseases, rheumatoid arthritis, asthma, and depression, are related to tumor necrosis factor, and C-reactive protein. These factors increase with *n*-6 fatty acid dietary intake and decrease with *n*-3 fatty acid dietary intake, either ALA or EPA and DHA.Most studies were carried out using EPA and DHA, being EPA and DHA more potent than ALA.

Data from the United States National Health and Nutrition Examination Survey show, when 2011–2012 and 2015–2016 are compared, that most children and adults consume recommended amounts of omega-3 as ALA. Nevertheless, in the group of children and teens (aged from 2 to 19), the average daily ALA intake from foods stayed steady for females (1.32 g and 1.30 g) but descended for males (1.55 g to 1.44 g). This could be considered as an alert for the nutritional fat quality intake among children and adolescents.

Conversely, in adults aged 20 and over, the average daily ALA intake from foods raised from 1.59 g to 1.66 in females and remained stable (2.06 g and 2.02 g) in males.

For practical reasons, it is possible to consider the ratio LA/ALA as indicative of the *n*-6/*n*-3 index. According to the 2015–2016 data, the values for males are 10.6 in the range of 2–19 years and 9.5 for the group over 20 years. For females these values are lower, at expenses of a lower intake of LA, namely, 9.5 for the 2–19 years group and 9.13 for adults of 20 years or more. These values are far off the recommended less than 5 for a healthy diet, and LCPUFA may be ingested as supplements. The average intake of EPA and DHA in the US population is 70 mg and contributes a very small amount to total daily *n*-3 recommended value that can be completed with fish oil supplements, commonly used in the United States.

In addition to LCPUFA source, dairy products and beef delivered most of the 500 mg per day mean BCFA intake, not negligible when compared to EPA and DHA.

Therefore it is important to have an optimum amount of fat and quality of fatty acids in the diet, being also significant to choose appropriate sources of fat in the diet.

11.1.3 Fatty acids and noncommunicable diseases prevention

Essential fatty acids exert a plethora of biological functions because they take place in many metabolic pathways. Among others, they prevent NCDs such as respiratory and cardiovascular failure, cancer, and diabetes, which are responsible for 71% of global deaths (41 million) each year. Moreover, in low and middle-income countries, they occur around 85% of premature deaths due to NCD. In these countries, people also bear the greater burden of undernutrition and other infectious illnesses. In wealthier countries, NCD disproportionately affects vulnerable and disadvantaged groups (WHO, 2018 https://www.who.int/country-cooperation/en/).

11.1.3.1 Cancer

EPA at a concentration of 100 μM and DHA at 50 and 100 μM induce potent apoptotic effects in the peripheral blood mononuclear cells of multiple myeloma patients. The mechanism is partially dependent on caspase activation (Mortaz et al., 2019). Conjugated fatty acids, including both conjugated linoleic acids (CLA) and conjugated linolenic acids (CLNA), have various health-promoting effects. There is growing evidence that CLA (rumenic acid) and CLNA such as eleostearic acid, punicic acid, jacaric acid, and calendric acid possess anticancer properties. These molecules induce apoptosis with DNA fragmentation involving lipid peroxidation and tumor cell arrest and death, both in vitro and in animal models. The conversion of CLNA into *cis*-9, *trans*-11 CLA was demonstrated in the intestinal Caco-2 cellular model (Dhar Dubey et al., 2019).

11.1.3.2 Obesity

The Western diet is typically rich in LA and its derivate AA *n*-6 fatty acids. This inflammatory response is related to obesity. The authors Kim et al. (2013) propose that cell phospholipids rich in these FA are more prone to induce the overstimulation of cannabinoid receptors CB1 and B2 via synthesis of anandamide (AEA) and 2-arachidonoylglycerol (2-AG). Overstimulation of the endocannabinoid system leads to increased appetite and body weight gain associated with fat accumulation and reduced glucose uptake in muscle. On the other side, the long-chain *n*-3 PUFA may function to alter the homeostatic induction of the endocannabinoid signaling system by modifying AEA and 2-AG binding to receptors to diminish overstimulation of this signaling pathway contributing to obesity.

In their experiment with obese, overweighed, and normal subjects, Banni et al. (2011) showed that four-week dietary intake of 2 g/day (309 mg/day of EPA/DHA 2:1) of krill oil (KO), a natural source of LCPUFA *n*-3, was able to significantly decrease 2-AG, but not AEA, only in the obese subjects. Also, a significant correlation between 2-AG levels and the plasma phospholipids *n*-6/*n*-3 LCPUFA ratio was observed only in obese subjects whose diet was supplemented with KO. This finding shows the implication of the relationship *n*-6/*n*-3 as an indicator of a preventive diet for the control of NCDs.

Concerning CLA, the *cis*-10, *trans*-12 isomer was implicated in the inhibition of lipogenesis, possibly as a result from the downregulation of genes involved in lipogenesis in goat mammary glands (Shi et al., 2017).

Depression, obesity, and LCPUFA *n*-3 intake were related for the first time in a study conducted (Tsujiguchi et al., 2019) in Japan between 2013 and 2016 with the participation of adults older than 65 years. The depressive state was determined using the Japanese short version of the Geriatric Depression Scale (GDS-15). They also assessed the intake of *n*-3 PUFA using the validated food frequency questionnaire. Results showed that 327 from 1633 participants (20.0%) exhibited depressive symptoms. Total *n*-3 PUFA, individual *n*-3 PUFA, and *n*-3/*n*-6 PUFA ratio were significantly inverse related to depressive symptoms in overweight/obese females but not in males. The reason of gender difference may be due to obesity and depression linked to inflammatory process. The immune response females may be stronger than in men leading to cytokine production, and therefore the effect of inflammation may affect differently obese female or men (Shelton and Miller, 2011). Dietary modifications may help to prevent depressive symptoms in overweight/obese females.

11.1.4 Fatty acid metabolism: from dietary lipids to target tissues

Recent insights on fatty acids emphasize the impact of lipid structure on their digestive behavior including intestinal absorption. Dietary fats are an important energy source, and their digestion help in the release and absorption of nutrients. The absorption of fatty acids depends on a complex process including micellarization step in the stomach, uptake by the enterocytes, chylomicron formation, and transport to the target tissues of the body.

11.1.4.1 Lipid digestion and lipolysis

In the first step of digestion, the oral phase allows lingual lipase from saliva to help TAG hydrolysis but also plays a role in human fat perception releasing nonesterified fatty acid (FA) (Kulkarni and Mattes, 2014). The lipid digestion starts in the stomach, being dietary triacylglycerols (TAGs), phospholipids (PLs), and cholesterol-ester (CHOLE), the three substrates of gastric, pancreatic lipases (Human pancreatic lipase: HPL and others related protein 1 and 2: PLRP1, PLRP2; carboxyl ester lipase (CEL); phospholipase A2). Digestive lipases such as gastric and pancreatic lipase are stereospecific of the external chain of TAG (*sn*-1 and *sn*-3) (Couëdelo et al., 2017).

Underestimated for a long time, gastric lipase from the stomach plays an efficient role in lipid emulsification and stimulation of pancreatic enzymes. Moreover, gastric lipase plays a primary role in the newborn in regard to their temporary pancreatic insufficiency (Fave et al., 2007). Gastric lipase preferentially hydrolyzes FA at the *sn*-3 position releasing free FA and diacylglycerols with a pH optimum ranging from 3 to 6 (Wang et al., 2013). Free FA in gastric chyme stimulates the release of cholecystokinin from duodenum favoring simultaneous excretion of pancreatic lipase and biliary secretion: bile salt, cholesterol, and PL (Marcil et al., 2004). HPL hydrolyzes about 70%−80% dietary TAG mainly in *sn*-1 and *sn*-3 and acts at interface oil/water releasing 2 molecules: free FA and *sn*-2 monoacylglycerols (2-MAG) (Auclair et al., 2018). Note that the cofactor colipase present in pancreatic juice is required to facilitate the action of HPL (Golding and Wooster, 2010). PLs represent the second source of FA, and pancreatic phospholipase A2 cleaves principally lecithin at the *sn*-2 position to yield FA and lysolecithin. The last and third FA source comes from hydrolyzing of cholesterol ester by CEL into free FA and free cholesterol (Wang et al., 2013).

The region distribution greatly influences the bioavailability of FA firstly at the lipolysis step (Michalski et al., 2013). When TAG contains long-chain, polyunsaturated fatty acids (PUFAs), pancreatic lipase has a lower hydrolytic activity (Mu and Porsgaard, 2005). In addition, when long-chain saturated fatty acids SFA (palmitic acid C16:0 and stearic acid C18:0) localized in *sn*-1 and *sn*-3 position are hydrolyzed by lipases, they tend to form complexes with calcium to constitute soaps, which were eliminated in stools (Michalski et al., 2013). However, mainly in newborn, these SFAs are more efficiently absorbed in the *sn*-2 position. For this reason, these SFAs are better absorbed in human milk (where 70% of C16:0 and C18:0 are in *sn*-2) than those of cow milk infant formula (40% of C16:0 and C18:0 are in *sn*-1 and *sn*-2) (Armand, 2013).

Emulsification is a key step in lipid digestion and dispersion process. It consists in reducing lipids microdroplet size to nanodroplet. This emulsification influences the FA bioavailability since intestinal absorption is modulated by emulsion droplet size, interface composition. Dispersed lipid droplets improve oil/water interface where lipolytic enzymes act. The optimization of emulsion structure to release lipids has generated scientific attention by researchers (Golding and Wooster, 2010; McClements and Li, 2010).

The emulsification is initiated by bile salt production in the duodenum where the lipolysis products (TAG, MAG and FA) can solubilize in mixed micelles (8−20 nm) or for cholesterol and PL in vesicles (40−200 nm), forms uptaken by enterocyte (Armand, 2013). Mixed micelles depend on the proportion of bile and PL and represented a transport vehicle for FA across the unstirred water layer toward the brush border of enterocytes (Wang et al., 2013).

11.1.4.2 Intestinal uptake and transport

Intestinal FA absorption is a complex process including uptake, intracellular trafficking, and synthesis and secretion in chylomicrons (CM). The mixed micelles facilitate FFA and 2-MAG transport across the unstirred water layer. Thus mixed micelles structures are dissociated before uptake by the apical membrane of enterocyte (Niot et al., 2009). Passive diffusion of protein-mediated mechanisms are the two pathways for uptake and transport across the brush border membrane (BBM) of the enterocyte. Note that passive diffusion occurs mainly for short-chain FA (SCFA) while FA transporters are also required for medium-chain FA (MCFA) and long-chain FA (LCFA). SCFA may be absorbed directly crossing the apical membrane and be released in the hepatic portal vein toward the liver and join to the circulation bound to albumin (Wang et al., 2013).

11.1.4.3 *Presentation of the protein involved in fatty acid absorption by enterocyte*

The lipid-binding proteins identified in the absorption process of FA are cluster determinant 36 (CD36), plasma membrane-associated fatty acid-binding protein (FABPpm) and fatty acid transport protein 4 (FATP4) (Tran et al., 2012). CD36 is ubiquitously expressed in different tissues (enterocyte myocytes or adipocyte), and it is known to be cholesterol, phytosterol, and carotenoid transporter. Localized in the BBM, CD36 is able to bind ionized LCFA, but recent data indicate that its main role in the LCFA absorption mechanism could be the inactivation of CM formation/secretion. Moreover, in the postprandial step, CD36 could act lipid sensing by transducing signals related to dietary lipid intake optimizing the formation of CM (Buttet et al., 2014). FABPpm has a dual location in the BBM but also in the lateral membranes of enterocytes indicating another role than FA uptake. Further research is needed to elucidate the exact function of FABPpm in FA absorption (Tran et al., 2012). The cellular location of FATP4 is controversy: BBM and/or endoplasmic reticulum. FATP4 seems to imply not only in uptake but also in transforming FA in activated intermediates at the endoplasmic reticulum level. Together these findings show that further research is required to understand the multirole of these lipid-binding proteins.

11.1.4.4 *Intracellular trafficking and chylomicron synthesis*

Intracellular trafficking and CM assembly take place in the ER and Golgi apparatus, respectively, sites of FA reesterification and CM secretion. After uptake by BBM of the enterocyte, FFA and 2-MAG were processed by two cytosolic fatty acid-binding protein FABP (I-FABP and L-FABP) transporting preferentially unsaturated FA. Mostly, LCFA delivered from the apical side of enterocyte is bind to I-FABP to be a vehicle toward ER where LCFA are reesterified in TAG. L-FABP could play rather a role in the synthesis/secretion of CM (Buttet et al., 2014).

The FA must be activated by acyl-CoA synthase from plast to form acyl-CoA esters in ER. Thus MAG and acyl-CoA synthase produce DAG and TAG. Following their esterification, TAG with PL and CE can be assembled with apolipoprotein to form complex structures called CM, which facilitated their transport in blood circulation. A microsomal triglyceride transfer protein named MTP is required to associate TAG with Apo-B48, essential structural protein to form pre-CM. MTP is indispensable to enhance lipoprotein genesis. In fine, the pre-CM were shuttled to the Golgi apparatus with the help of SAR1B initiating the formation of vesicles. If MTP is considered as the first limiting step of lipid intestinal absorption, the transfer by SAR1B represents the second limiting step (Tran et al., 2012; Auclair et al., 2018). Then CM is secreted into the lymph to reach a TAG concentration blood peak after 3−4 hours, then TAG is hydrolyzed by lipoprotein lipase (LPL) enzyme localized on the surface of capillary endothelial cells of adipose tissues and muscles.

11.1.4.5 *Distribution to target tissues and utilization*

Distribution of FA to the liver, skeletal muscles, and adipose tissues represents the key FA metabolism to maintaining metabolic homeostasis. FA is used as energetic subtract by heart and muscles to produce ATP (via the β-oxidation pathway). FA is needed in the liver for the biosynthesis of lipoprotein VLDL, Apo B-100, or HDL (mainly involved in TAG and cholesterol transport). FA is used in adipose tissues for storage in TAG form. FA also plays a role in the mammary gland, during lactation to produce TAG of milk fat globule for newborn feeding. In fine, FA is needed for edification of the cellular membrane in all organs via PL production containing oleic acid C18:1; linoleic acid C18:2 *n*-6 (LA); arachidonic acid (ARA); C20:4 *n*-6 and docosahexaenoic acid (DHA); C22:6 *n*-3 and SFA to ensure good membrane fluidity (Armand, 2013).

If oleic acid is easily brought by food, LA and α- linolenic acid C18:3*n*-3 (ALA) cannot be synthesized by a human. These FAs are precursors of DHA and eicosapentaenoic acid C20: 5 *n*-3 (EPA) synthesized by a series of desaturase and elongase enzymes but the conversion efficiency is low, so dietary intake from mainly aquatic source appears more effective (Abedi and Sahari, 2014). DHA is essential for the infant development of the brain, eye, and nervous system. DHA status of pregnant women is a great relevance for infant brain development (Arab-tehrany et al., 2012). DHA represents 15% of total FA in brain tissue participating with PL in the structure of the neuronal membrane. DHA-containing membrane glyceroPL is found in the retina, testes, brain, heart, and skeletal muscle and might regulate functions in each tissue (Hishikawa et al., 2017).

TAG is stored in adipose tissues in lipid globule form, and FAs are released in circulation depending on hormonal lipase and the number of adipocytes in the organism. Thus obese subjects have a more important release of FAs and reach a higher plasmatic concentration of FA. The circulated FA is uptake by the liver to be oxidized in H_2O and CO_2 or in ketone bodies. This metabolic process takes place in mitochondria via β-oxidation. Other hepatic TAGs are incorporated in lipoproteins to be released in circulation. Skeletal muscles are able to store FA in TAG form in addition to glucose, the main energetic substrate. FA as a substrate is used when the muscle is not active or during long physic exercises. FA and glucose can compete for their utilization in muscle tissue. If FA plasmatic concentration is high, their oxidation is increased in muscle in the detrimental of glucose. That is the reason why in the obese subject, glucose utilization is decreased and leads to glucose intolerance or insulin resistance phenomenon (Walrand et al., 2010).

11.1.4.6 Main sources of animal polyunsaturated fatty acids in Western diets

Pasture feeding is a strategy to increase *n*-3 PUFA in ruminant's meat and milk (García et al., 2017). In addition, it improves fat-soluble vitamins in the meat (reviewed in Descalzo and Sancho, 2008). Data in Fig. 11.1 show that

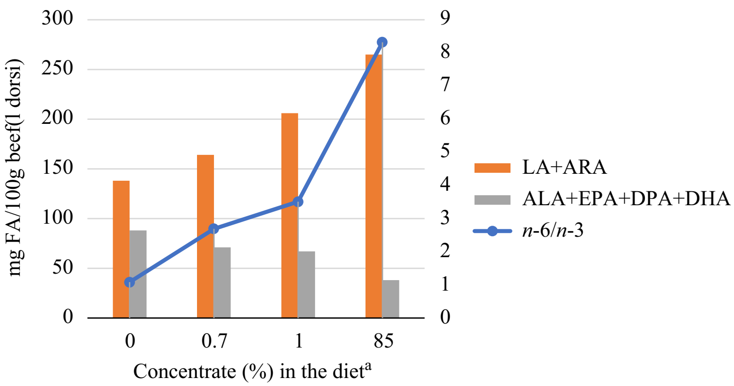

FIGURE 11.1 *Longissimus dorsi n*-6/*n*-3 ratio in beef from steers feed with increasing level of corn supplementation. [a] concentrate was mainly corn silage and pasture feeding mainly lucerne and tall fescue.

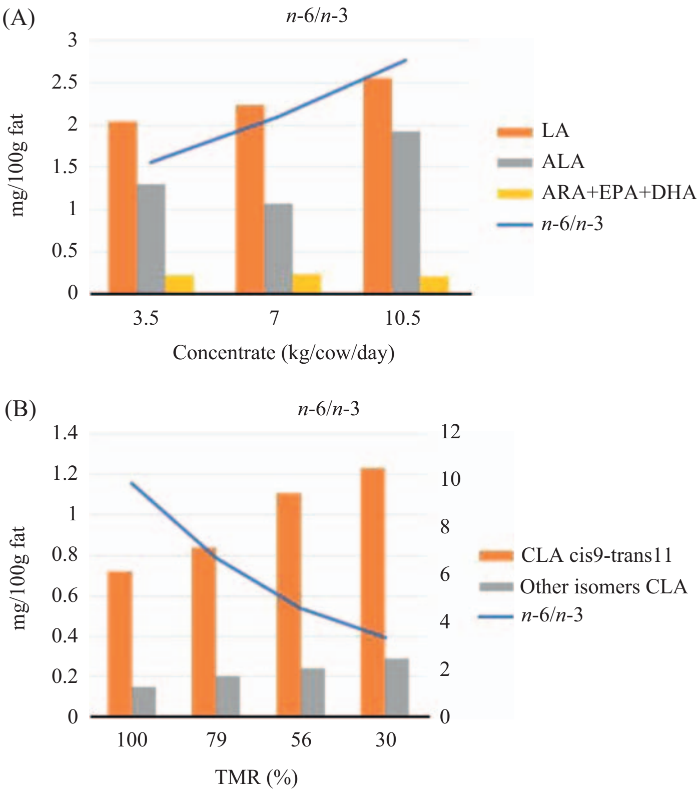

FIGURE 11.2 The *n*-6/*n*-3 index in milk with increasing concentrate feed as source of LA *n*-6 FA (A) or pasture as source of ALA *n*-3 FA (B).

the increase of concentrate in the diet induced an increment in the *n*-6/*n*-3 index almost eight times higher in a concentrate feed (mean of 8.32) compared to only pasture finishing (1.08) diet in meat (*Longissimus dorsi*) of different beef genotype (Aberdeen Angus, Charolais × Aberdeen Angus, and Argentine Holstein).

Similarly, milk from Argentine Holstein cows with high concentration levels in the feed presented a higher *n*-6/*n*-3 relationship. This occurred at expenses of an increase in LA and a decrease in ALA. LCPUFAs are minor constituents and do not influence the index (Fig. 11.2A) (Salado et al., 2017). Concentrate feed consisted mainly of grains and pellets, which are sources of high concentration of LA (*n*-6) at expenses of ALA (*n*-3). On the contrary, the presence of pasture in the diet favored the incorporation of *n*-3 FA in milk (Fig. 11.2B). Pasture is rich in LA and ALA, and their balance helps to increase the nutritional value of ruminant's meat and milk (Salado et al., 2018).

Fig. 11.2 presents the *n*-6/*n*-3 index in milk with increasing concentration in the feed as a source of LA *n*-6 FA (A) or pasture as a source of ALA *n*-3 FA (B).

The *n*-6/*n*-3 relationship increases with the increase of concentrate in the feed. As pointed previously, modern productive strategies that favor feed lot, and confined intensive systems are detrimental for the nutritional quality of meat and milk.

Therefore pasture feeding and strategic supplementation of ruminant animals may improve the fatty acid composition of meat and milk and its derived products. This point is important for systems that are compatible with agroecological production and for traditional milk and meat production based on grasslands.

Published studies were carried out with the objective of improving FA profile in beef through the use of oil sources to animal feeding, such as marine algae, chia seeds, lupin, hemp, flax, among others. Results differ and are being discussed since benefits are not clear in order to produce the costs and stability of the final product (Givens, 2009, Wolmarans, 2009). Wood et al. (1999) demonstrated that feeding diets rich in $n-3$ PUFA (whole linseed source) reduced shelf-life of lipids in ruminants. However, Dunne et al. (2011) found that when feeding between 9 and 37 g of rumen-protected fish oil per kg of diet to beef heifers, EPA and DHA increased in the phospholipid fraction of the neck muscle but lipid oxidation under simulated retail display conditions increased only at the highest administrated dose (37 g/kg rumen-protected fish oil). Studies with unprotected fish oil carried out by Vatansever et al. (2000) and Phelps et al. (2016) showed a reduction in color stability, While several studies demonstrated that feeding strategies with PUFA to ruminants led to undesirable volatile compounds in the produced meat (Elmore et al., 1999, 2005; Campo et al., 2006; Mezgebo et al., 2017).

On the other hand, several studies explored the possibility of increasing PUFA $n3$ availability in western diets by means of fisheries and aquaculture. Since PUFA $n3$ from seafood is expensive, unsustainable, and not very affordable, new feeding strategies are under evaluation in this issue. Emerging results are promising despite its contribution to a global level that remains debated (Béné et al, 2016; FAO, 2019).

11.2 Implications of natural antioxidants to maintain the nutritional and sensory quality aspects of food

Lipid oxidation is one of the most important processes occurring in the food matrix responsible for the quality deterioration and thus shortens the shelf-life (Domínguez et al., 2019a). In this regard, lipid oxidation is responsible for off-flavors and unacceptable taste as well as discoloration, loss of nutritional value, the formation of toxic compounds, drip loss, and so on, which could be affected by their acceptance by the consumer. Moreover, lipid oxidation products initiate the oxidation of proteins leading to serious health concerns, and deterioration of nutritive value (Barriuso et al., 2016; Xu et al., 2016). However, no flavor change is associated with protein oxidation, and hence its organoleptic properties remain mostly unaffected (Shahidi, 2016).

The oxidative stability is influenced by intrinsic and extrinsic factors. Regarding the intrinsic parameters, the fatty acid composition is one of the most important factors, since FA is the main substrate for the development of lipid oxidation. However, the content of other prooxidant compounds, such as metals and enzymes, or antioxidant compounds, such as vitamins, antioxidant enzymes, or peptides, are determinant in the development of the oxidative process. In addition, extrinsic factors such as processing and storage conditions (light, enzymes, temperature, metals, oxygen, and so on.) and the presence of antioxidants (inhibitors) or prooxidants (catalysis) can increase or decrease the oxidative stability of foods.

The autoxidation process is defined as a chain of free radicals and consists in a combination of three distinct phases: *initiation* in which free radicals occur, *propagation* in which the number of reactive compounds is multiplied, and finally *termination* in which the reactive compounds degrade or react with each other to give nonreactive compounds (Cheng, 2016). During the development of these phases, the free radicals could react with the hydrocarbon chain of the fatty acid-forming peroxides, which, in turn, react with other hydrocarbon chains abstracting hydrogens originating hydroperoxides. The hydroperoxide decomposition leads to the formation of hydrocarbons, aldehydes, alcohols, and volatile ketones, among others.

Although lipid oxidation generally has a negative impact on foods, in some cases it contributes to the development of pleasant aromas (Gómez and Lorenzo, 2013; Lorenzo and Carballo, 2015; Pateiro et al., 2015a,b; Bermúdez et al., 2015). In this regard, it is well known that the compounds derived from lipid oxidation play an important role in the development of the typical aroma of several products such as ham, sausages, cheese, and so on, which is one of the most appreciated consumers' attributes (Domínguez et al., 2019b).

To offer foods with acceptable sensorial properties and oxidative stability, several technologies were developed in order to decrease protein and lipid oxidation and extend shelf-life, such as modified atmosphere, vacuum packaging, and addition of antioxidants. In this regard, the lipid and protein oxidation can be retarded using natural antioxidant (at low levels) to extend the shelf-life decreasing the toxic compounds such as cholesterol oxidation products, which are linked to deleterious health effects such as atherogenic, carcinogenic diseases, cytotoxic, neurodegenerative, and mutagenic (Kulig et al., 2016).

Antioxidants can delay the lipid oxidation through the following mechanisms: decreasing localized oxygen concentrations, breaking chain reaction, preventing chain inhibition by scavenging initiating radicals, decomposing peroxides, and binding chain initiating catalysts, such as metal ions (Dorman et al., 2003).

The addition of antioxidants in food products is regulated by laws of international standards or countries (Karre et al., 2013). In this regard, the *Codex Alimentarius* allows only the addition of substances, which were assessed by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), and these may be added only in foods standardized by Codex (Miková, 2001). In the United States, regulation of antioxidants is stipulated by the Federal Food, Drug and Cosmetic Act, Meat Inspection Act, Poultry Inspection Act, and other state laws (Miková, 2001; Shahidi and Zhong, 2005). However, in the EU the use of antioxidants is subject to the European Parliament and Council Directive No. 95/2/EC of 20 February 1995 on food additives other than color or sweeteners.

Synthetic antioxidants such as butylated hydroxytoluene (BHT), propyl gallate, tertiary butyl hydroquinone (TBHQ), and butylated hydroxyanisole (BHA) were used in food processing. The maximum level is recommended to be no more than 200 ppm on the fat level and 30 ppm on the meat weight

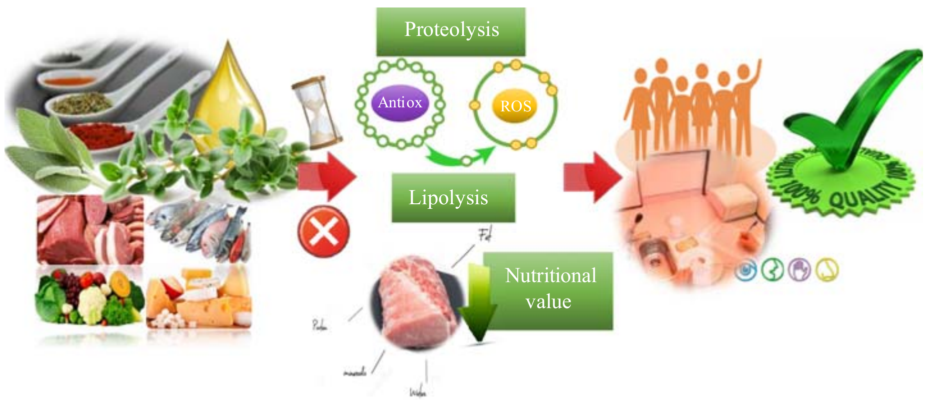

FIGURE 11.3 Application of natural antioxidants to maintain the nutritional and sensory properties of foods.

basis. In this regard, the inclusion of natural antioxidants is an interesting strategy to conventional antioxidants due to the toxicological effects of synthetic antioxidants. Although natural antioxidants are less efficient and more expensive, these extracts are considered safer and better accepted by consumers. In addition, some natural antioxidants showed higher activity compared to synthetic antioxidants (de Carvalho et al., 2019; Fernandes et al., 2018; Pateiro et al., 2018; Zamuz et al., 2018).

Technological alternatives involve the addition of antioxidants directly into the food matrix or through coating packaging materials with natural antioxidants obtained from plant extracts to decrease the lipid and protein oxidation of the food products (Fig. 11.3). Thus the application of these natural products is a good strategy to decrease the loss of the sensorial and nutritional properties of foods due to protein and lipid oxidation processes (Karre et al., 2013; Lorenzo et al., 2018; Nikmaram et al., 2018).

The protection of compounds associated with nutritional effects in human health is one of the relevant aspects associated with natural antioxidants (Table 11.1). Moreover, these compounds are also related to preservation, and even improvement, of sensory properties of food products. This beneficial effect was reported for the inclusion of green tea extract (1000 mg/kg) in pig liver pâté during refrigerated storage (Pateiro et al., 2014). The authors also evaluated the potential effect of grape

TABLE 11.1 Impact of natural extracts in the nutritional and sensory characteristics of food products.

Product	Extract	Effect	Reference
Pig liver pâté	Grape seed, chestnut, and green tea extract (1000 mg/kg)	Reduced the loss of PUFA during storage	Pateiro et al. (2014)
Chorizo	Grape seed, chestnut, and beer residue extract (50, 200, and 1000 mg/kg)	Enhanced the preservation of PUFA during storage	Pateiro et al. (2015a,b)
Beef patties	Chestnut extracts (250, 500, and 1000 mg/kg)	Reduced the degradation of fatty acids (particularly linoleic acid); nonsignificant effect on sensory attributes	Zamuz et al. (2018)
Soybean oil	Hydroethanolic rosemary extract (50 and 100 mg/kg)	Preservation of total tocopherols; nonsignificant effect on sensory attributes	Dias et al. (2015)
Hazelnut oil	Rosemary essential oil (10 and 50 g/kg)	Reduced the loss of α-tocopherol and C18:2 n6c caused by frying process; nonsignificant effect on French fries	Tohma andTuran (2015)
Strawberry	*Paeonia rockii* (0.25%) extract in a coating matrix	Reduced the loss of vitamin C during storage	Pagliarulo et al. (2016)
Pears	Rosemary extract (0.03%) in a coating matrix	Reduced the loss of vitamin C; assisted in the preservation of color and visual appearance	Xiao et al. (2010)
Pumpkin	Red algae extract (40%) Surface agent	Reduced the loss of carotenoids; slight reduction in the sensory properties	Wang et al. (2011)
Lettuce	Green tea extract (0.25, 0.5, and 1 g/100 mL)	Preservation of ascorbic acid and tocopherols; similar sensory attributes observed after chlorine treatment	Martín-Diana et al. (2008)

PUFA, polyunsaturated fatty acids.

seed and chestnut extracts but did not observe significant protective effects. A similar effect was reported in another experiment carried out with grape seed and beer residue extracts during the storage of Spanish *chorizo* in comparison to control samples without antioxidants (Pateiro et al., 2015a,b). The protective effect was observed in the PUFA components (easily degraded by oxidizing agents) during the ripening and vacuum-packaged period (on days 19 and day 50) using 1000 mg/kg of grape seed extract and 200 mg/kg of beer residue extract. The preservation of PUFA was also reported by other authors using a chestnut extract (Zamuz et al., 2018). In this experiment, three extracts were prepared from bur, leaf, and hull (250, 500, and 1000 mg/kg) and added to patties. The loss of PUFA was reduced in the patties added of bur and leaf extracts at all concentrations tested, particularly after 9 days of storage. Moreover, the authors indicated that nonsignificant modifications in sensory properties were associated with chestnut extracts.

Also, the addition of Moringa oleifera leaf powder into the meat preparation preserved the oxidative stability of pork droëwors during drying and storage through enhancement of its intrinsic antioxidant mechanism (Mukumbo et al., 2019).

The potential use of natural extracts in the preservation of the nutritional value of edible oils is also reported in the scientific literature. This effect was observed for rosemary hydroethanolic extract (50 and 100 mg/kg) in soybean oil subjected to accelerated storage conditions (Dias et al., 2015). After 20 days of storage, the total tocopherol content (as well as α-, γ- and δ-tocopherol) was significantly higher in samples with rosemary extract than control (without added antioxidants). The results obtained with rosemary extract were also comparable to those obtained with TBHQ, the commercial and synthetic antioxidants usually added to edible oils. The nonsignificant effect was reported for the acceptance of color, aroma, and flavor in the sensory evaluation. Similarly, the inclusion of ground rosemary tissue into hazelnut oil improves the preservation of α-tocopherol during the frying process (Tohma and Turan, 2015). This effect was mainly observed in samples with 50 g/kg of ground rosemary tissue. The retention of α-tocopherol and C18:2 n6c was higher using ground rosemary tissue than using rosemary methanolic extract and essential oil. The sensorial evaluation of French fries fried in hazelnut oil added of any form of rosemary additive did not receive different scores in comparison to control samples.

Regarding the use of natural extracts to preserve nutritionally relevant components in vegetables, interesting results were also reported. For instance, the use of edible coating containing *Paeonia rockii* extract (0.25%) improved the retention of vitamin A in strawberries during 16 days of refrigerated storage (Pagliarulo et al 2016). In pears, an edible coating produced with rosemary extract (0.03%) improved the preservation of vitamin C after 3 days of refrigerated storage (Xiao et al., 2010). The authors also indicated that pears coated with rosemary extract also received higher scores on color and visual appearance in the sensory analysis.

In the case of dried pumpkins, the loss of carotenoids was reduced by using a red alga extract as a surface agent (Wang et al., 2011). However, this study also indicated that sensory attributes were slightly reduced (color, odor, texture, appearance, and overall acceptability) in treated samples. Finally, the use of green tea extract (0.5 g/100 mL) in the washing stage of lettuce improved the preservation of ascorbic acid and tocopherols during 10 days of storage at 20°C (Martín-Diana et al., 2008). The authors also observed that the strategic addition of green tea extract in the washing stage did not reduce the scores of treated lettuces in comparison to control washing solution with chlorine. In this sense, it is reasonable to consider that natural extract could be explored in the food industry to preserve the nutritional value of food products from animal and vegetable origin.

11.3 Application of emergent technologies and their effect on the fatty acid profile of different muscle foods

Food safety involves the physical and economic access to food that meets the nutritional requisites and the preference of the consumer. In this sense, food security relates to health through malnutrition, and to sustainable economic development, environment, and commerce (Pighin et al., 2016).

Fresh meat is a highly perishable product with a limited shelf-life; then it is essential that conservation technologies are properly applied to maintain their safety and quality. In this context, meat processing and preservation technologies must provide sufficient quantities of good quality and affordable meat products to consumers. The hurdle approach has been investigated to increase their efficacy.

Thermal processes are still one of the dominant technologies chosen for ensuring shelf-life. The main objective of heat treatment is to ensure the destruction of microorganisms and inactivation of enzymes in order to avoid spoilage reactions and growth of pathogens and microorganisms. Even though, applying the thermal process may affect the nutritional and sensory characteristics of food (Aguilar et al., 2012).

Several novel nonthermal technologies were proposed in meat product processing and preservation. As stated by Troy et al. (2016) these technologies are challenged to fulfill consumer demands of high quality, nutritious, and safe products, while considering energy-efficient processes that minimize the use of natural resources. Among these technologies, high-pressure processing (HPP), ultrasound, cold plasma, pulsed electric field (PEF), and ozone processing have some promising commercial applications (Troy et al., 2016).

Several authors analyzed the effect of HPP on meat protein: HPP induces changes in the secondary, tertiary, and quaternary structures of meat proteins by influencing protein conformations and various molecular interactions. These modifications could be reflected in changes in the same quality and technological characteristics of meat products such as texture, water holding capacity, and gelation capacities (Campus, 2010; Bajovic et al., 2012; Ma et al., 2007). Also, it was established that HPP treatment decreased oxidative stability of muscle foods, including beef, pork, chicken, and cod. However, the extent of the oxidation process and the technical conditions (pressure level and temperature range) that triggered this process varied according to the species (Bajovic et al., 2012).

HPP could induce modifications of the fatty acid profile, micronutrients, and vitamin contents of meat that could affect its nutritional value and its impact on the prevention of lifestyle-related diseases.

Zhang et al. (2016) evaluated the effect of HPP processing (up to 600 MPa) on squids during refrigerated storage; squid products are considered a source of high amounts of good quality protein and healthy *n*3-series PUFAs. The authors reported that HHP reduced the content of cholesterol and purine, delaying the losses of vitamin B2 and antioxidant activity. Also, no statistically significant differences were detected in EPA (eicosapentaenoic acid, 20:5 *n*-3) or DHA (docosahexaenoic acid, 22:6 *n*-3) contents between pressurized and untreated samples.

Studies carried out on salmon showed no significant changes in the fatty acid profile due to HPP. Yagiz et al. (2009) evaluated Atlantic salmon dark muscle during 6 days of storage at 4°C. The authors reported that HPP treatments (150 MPa and 300 MPa for 15 min) had no effect on total saturated fatty acid composition, also in 20:1*n*-7 and 22:1*n*-11 values during storage.

McArdle et al. (2010, 2011) evaluated the effect of HPP processing combined with temperature (200−600 MPa and 35°C−55°C) on beef M. pectoralis profundus muscle. No differences in fatty acid composition, PUFA/SFA, and *n*-6/*n*-3 ratio due to HPP processing were reported. Similar results were obtained for Lamb M. pectoralis profundus treated with 200−600 MPa and 20°C−60°C (McArdle et al., 2013).

Among emerging technologies, the application of pulsed electric field (PEF) on food has been widely studied; even though the application in solid food such as meat is generally lacking (Bhat et al., 2019). In general, this technology involves the use of electric field pulses of short duration (ranging from nanoseconds to milliseconds) with an electric field strength of 0.1−80 kV/cm (Bhat et al., 2019). PEF has the advantages that the time of processing is short; it has low energy consumption; and it can be considered a green technology. In addition, the thermal effect on the food matrix could remain low compared to other technologies such as ohmic heating; except when high-intensity treatments are considered (Gómez et al., 2019).

PEF processing affects the structure and texture of meat. The improvement of meat tenderization depends on pulse characteristics, the energy applied in the process, the muscle type, and rigor conditions, and it could be related to the enhancement of cell permeation and consequently the increase of proteolysis. An insight into the influence of PEF on calpain activity during aging and a revision of the underlying mechanisms proposed were analyzed in Bhat et al. (2018) and Bhat et al. (2019).

In addition, changes in the cell permeability could promote the oxidation of fatty acids or facilitate the reaction between enzymes and their substrates. Then, an increase in lipid oxidation and changes in fatty acid profiles could be expected during the PEF application (Kantono et al., 2019; Bekhit et al., 2016; Faridnia et al., 2015).

Kantono et al. (2019) studied the effects of PEF processing (0.8−1.1 kV/cm, 20 μs, 50 Hz, and 130 kJ/kg.) and frozen storage on beef biceps femoris and semitendinosus muscles. The results indicated that most fatty acids were affected by both PEF treatment and storage period, with differences between the muscles. PEF increased lipid oxidation and the presence of short-chain fatty acids. In semitendinosus muscle, the *n*-6/*n*-3, PUFA/SFA and MUFA/SFA ratios were modified. In contrast, Faridnia et al. (2015) showed no effect on PUFA/SFA and *n*6/*n*3 ratios of semitendinosus beef muscle treated with PEF (1.4 kV/cm, 20 μs, 50 Hz, and 250 kJ/kg).

The influence of PEF processing combined with heat treatment on Abalone meat was studied by Luo et al. (2019). The authors pointed out that Abalone is expensive seafood with many health benefits such as fatigue recovery and detoxification. The results showed that PEF treatment had a marginally significant effect on C16:0, C18:1*n*-9, C20:0, and MUFA content. Even though, the total FA and total SFA content increased at a specific combination of PEF and heat treatments.

In view of the results described previously in muscle foods and the literature cited, HPP could be considered a mild process in terms of its effect on fatty acids profile. In the case of PEF technology, more research is needed for determining its impact on meat quality and define optimal application conditions in the meat industry, since the process parameters may vary notably according to the desired purpose (preservation, tenderization). Given the impact that both technologies could have on lipid oxidation, it will be necessary to complement them with other strategies to minimize or control their effect.

11.4 Conclusion and perspective

Food security is indubitably a matter of preventive nutrition in order to avoid NCD and physiological disorders in the body. Despite the abundant information available, knowledge about the effect of fats on human health is weak among the population. Growing evidence supports that the type of foods supplying fats and carbohydrates would be finally more important than the total amount of fat and carbohydrates contained in the diet. Special care should be taken in *n*-6/*n*-3 fatty acid consumption, since an unbalanced intake may lead to physiological disorders, especially those with more than 18 carbons that are essential for human development and NCD prevention (mainly EPA, DHA, DPA, and CLA). These fatty acids derive mainly from animal sources and marine algae, and their bioavailability and metabolism should be further studied. Due to their highly unsaturated nature, they are prone to oxidation. Therefore it is necessary to deep research on technological solutions of processing and preservation in order to preserve the integrity of highly unsaturated fats. The addition of antioxidants and plant extracts seems to be promising because they are effective in preventing lipid oxidation. Accordingly, food security research needs a multifactor approach to biological activity, processing, preservation, consumers' acceptance, and affordability in order to achieve better food products.

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Food Security and Nutrition

Edited by Charis M. Galanakis

A guide to global food security, with an emphasis on nutrition security as an integral component

Food and nutrition security—identified via availability, access, utilization, and stability—and transitions to sustainable food systems are major discourses in the agro-food arena, as many countries face the impacts of climate change and simultaneously experience different forms of malnutrition. ***Food Security and Nutrition*** explores relevant trends in a coherent and systemic framework, giving emphasis on climate-resilient and nutrient-dense crops, processes and policies that affect the functioning and dynamics of agri-food markets. Linking agricultural input subsidies to agricultural productivity, the book also explores the relationships between food and nutrition security and wildlife conservation, food loss and food waste.

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About the editor

Charis M. Galanakis is a multidisciplinary scientist in agricultural sciences as well as food and environmental science, technology, and sustainability, with experience in both industry and academia. He is the research and innovation director of Galanakis Laboratories in Chania, Greece, an adjunct professor of King Saud University in Riyadh, Saudi Arabia, and the director of Food Waste Recovery Group (SIG5) of ISEKI Food Association in Vienna, Austria. He pioneered the new discipline of food waste recovery and has established the most prominent innovation network in the field. He also serves as a senior consultant for the food industry and expert evaluator for international and regional funded programs and proposals.

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