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Enhancing Food Security Through Postharvest Technology: Current and Future Perspectives

Gopinadhan Paliyath[1], Autar K. Mattoo[2], Avtar K. Handa[3], Kalidas Shetty[4], and Charles L. Wilson[5]

[1] Department of Plant Agriculture, University of Guelph, 50 Stone Road East, Edmond C. Bovey Building, Guelph, ON, N1G 2W1, Canada
[2] Sustainable Agricultural Systems Laboratory, USDA-ARS, Beltsville Agricultural Research Center, Beltsville, MD, 20705, USA
[3] Center of Plant Biology, Department of Horticulture and Landscape Architecture, Purdue University, 625 Agriculture Mall Drive, West Lafayette, IN, 47906, USA
[4] Department of Plant Science and Global Institute of Food Security and International Agriculture, North Dakota State University, 214/218 Quentin Burdick Building, 1320 Albrecht Boulevard, Fargo, ND, 58108, USA
[5] World Food Preservation Center® LLC, Box 1629, Shepherdstown, WV, 25443, USA

1.1 Introduction

Food security has become a common concern among academicians, socio-economists, and scientists, capturing worldwide attention among politicians and lawmakers alike. Food security refers to less availability of food and the options available or not available for enhancing its security. There is no one clear definition for a lack of food security, as the causative factors are multiple and broad. In general, the ultimate result of these factors is the lack of adequate food and nutrition for humans and livestock, with the result that poverty, hunger, and impaired development of children afflict the poorer nations and result in trauma. One may envision that food security is not as much an issue in the advanced world as it is in pockets of other, less advanced regions, where people do not have access to adequate daily requirements of food. In this chapter, we focus on some key causes of the lack of food security and how these causes may be averted, since many are anthropogenic in origin.

During the 1996 World Food Summit, the Food and Agriculture Organization (FAO) defined food security as, "Food security exists 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 a healthy and active life." The main points of vulnerability were categorized into availability, stability, utilization, and access (Schmidhuber and Tubiello 2007). These in turn depend on several critical points in the agriculture and food value chain. In general, factors affecting food production – short-term and long-term storage, distribution, processing, wastage, etc. – play critical roles in achieving food security.

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The optimization of each step would, in theory, provide the maximum available food to those people who have access to the food and those in need of it globally. In recent years, a number of sources have insisted that food production across the world should be increased. However, there are no clear-cut strategies to enable this since many of those strategizing "increasing the production" are from the private industries, who could be perceived as profiting from such a strategy. The world has lost much of its rainforests due to non-sustainable methods of agriculture, and these have been identified as a major source of global warming and climate instability. Very little has been done to increase awareness of reducing the wastage, of applying technologies to enhance the shelf-life and nutritional quality of highly perishable agricultural and harvested produce, of increasing processing capacity at the domestic level and, wherever possible, of adapting a sustainable agricultural and harvesting (sea, livestock) system suitable for a nature-adapted living. In this context, it is important to note that 40–50% of food produced is wasted and/or lost (Gustavsson et al. 2011). We argue that by developing and adapting appropriate storage technologies it may be possible to reduce the loss of food produced. Nonetheless, the challenge of feeding the world population, which is expected to vary from 8 to 10 billion by 2050, is enormous (Roberts and Mattoo 2018). Production technologies that help decrease the negative impacts on land, water, and climate are an important factor for increasing food production needs (Foley et al. 2011; Roberts and Mattoo 2018). Importantly, agricultural production must not only double to meet projected demands for food (Foley et al. 2011) but food quality must also be improved, with a higher nutrient content (Tester and Langridge 2010; Roberts and Mattoo 2018).

New strategies and approaches are needed to improve the nutritional quality of food and in particular to counter the emergence of serious diet-linked non-communicable chronic diseases (NCDs). These can be seen as new aspects of global food security that are contributing directly to the global epidemic of type 2 diabetes and its complications (Shetty 2014). Importantly, it is clear that modern commercial varieties are significantly reduced in flavor molecules as compared to much older varieties (Shetty 2014; Tieman et al. 2017). It is possible that classical breeding and selection may have led to the loss of important nutritional traits. Therefore, there is a need to use novel genetic approaches to recover such, and other, genes so that crops may be engineered to enhance nutritional content in order to address contemporary malnutrition-linked food security challenges as well as rapidly emerging high calorie diet-based NCD challenges. Examples of engineered traits are many, including "golden" rice containing enriched protein and pro-vitamin A (β-carotene) to fight malnutrition in the developing world (Paine et al. 2005); multivitamin corn with high β-carotene, ascorbate, and folate (Naqvi et al. 2009); and tomato fruit with enriched nutrients – anti-cancer lycopene, amino acids, and organic acids (Mehta et al. 2002; Mattoo et al. 2006). Three case studies that investigated sustainable, next-generation small grain, tomato, and oilseed production systems utilizing sustainable cover crop systems/management and plant-beneficial microorganisms concluded that the yield in these production systems did not increase further compared with current production systems (Roberts and Mattoo 2018), suggesting that multiple sustainable approaches are needed to overcome the food security issues facing humans.

Data from several sources related to the overall assessment of the multiple factors that are causes and effects of food insecurity are summarized in Tables 1.1 and 1.2 and Figures 1.1–1.4). Tables 1.1 and 1.2 summarize a 14-year trend in several parameters

Table 1.1 Trends in world human activity and repercussions 1990–2014.

	1990	**2000**	**2014**
The setting			
Population, total (minimum)	5 320.8	6 127.7	7 243.8
Population, rural (minimum)	3 033	3 263.4	3 362.5
Government expenditure on agriculture (% total outlays)			
Area harvested (minimum ha)	1 952	2 061	2 781
Cropping intensity ratio	0.4	0.4	
Water resources (1000 m^3 per person per year)			
Area equipped for irrigation (1000 ha)			
Area irrigated (% area equipped for irrigation)			
Employment in agriculture (%)	*35.3*	38	*30.7*
Employment in agriculture, female (%)	*9.2*	20.3	*25.2*
Fertilizers, nitrogen (kg of nutrients per ha)		*64.9*	*85.8*
Fertilizers, phosphate (kg of nutrients per ha)		*25.9*	*33.2*
Fertilizers, potash (kg nutrients per ha)		*18.2*	*20.4*
Energy consumption, power irrigation (minimum kWh)	35 981	130 786	*325 448*
Agricultural value added per worker (constant $US)			
Hunger dimensions			
Dietary energy supply (kcal per person per day)	2 597	2 717	2 903
Average dietary energy supply, adequacy (%)	113	116	123
Dietary energy supply, cereals/roots/tubers (%)	*58*	55	*52*
Prevalence of undernourishment (%)	18.6	15	10.8
GDP per capita ($US, PPP)	8 832	10 241	*13 915*
Domestic food price volatility (index)		3.6	*7.8*
Cereal import dependency ratio (%)	*−0.4*	−0.2	*50.7*
Underweight, children under five (%)			
Improved water source (% population)	78.5	83	*88.7*

GDP, gross domestic product; PPP, purchasing power parity rates.
Note: Data in italics indicate the value for the most recent year available.
Source: FAO (2015) *FAO Statistical Pocketbook, World Food and Agriculture*. Reproduced with permission.

that indicate various aspects of resources and conditions that result from human activities worldwide.

Figure 1.1 shows the trends in childhood height/weight comparisons in various countries from data collected over a nine-year period. Children in several countries show symptoms of reduced growth (stunted or wasted), the problem being acute in countries where there are issues related to the availability of food and clean water. The standard used for comparison is not clear. If a comparison is made between children in an affluent country and those in an underdeveloped country, there are likely to be differences.

Table 1.2 Trends in world food supply 1990–2014.

	1990	2000	2014
Food production value, 2004–2006 (minimum 1$)	1 294 508	1 618 814	*2 246 912*
Agriculture, value added (% GDP)		4	4
Food exports (minimum $US)	215 425	276 704	*945 572*
Food imports (minimum $US)	237 329	294 271	*966 964*
Production indices (2004–2006 = 100)			
Net food	73	90	*121*
Net crops	72	89	*123*
Cereals	82	92	*123*
Vegetable oils	51	77	*141*
Roots and tubers	74	94	*119*
Fruit and vegetables	58	86	*127*
Sugar	86	93	*132*
Livestock	76	92	*115*
Milk	83	89	*114*
Meat	74	91	*118*
Fish	72	92	*119*
Net trade (minimum $US)			
Cereals	−2 447	−4 525	*−6 979*
Fruit and vegetables	−9 430	−7 461	*−5 811*
Meat	−2 574	−682	*5 056*
Dairy products	−663	165	*1 169*
Fish	−3 882	−4 295	*1 257*
Environment			
Forest area (%)	33	32	*32*
Renewable water resources withdrawn (% of total)			
Terrestrial protected areas (% total land area)	9	12	*14*
Organic area (% total agricultural area)			*1*
Water withdrawal by agriculture (% of total)			
Biofuel production (1000 kt of oil equivalents)	3 987	18 110	*381 064*
Wood pellet production (1000 t)			26 154
Net GHG emissions from AFOLU (CO_2 eq., Mt)	8 075	7 449	*8 165*

AFOLU, agriculture, forestry and other land use; GHG, greenhouse gas.
Note: data in italics indicate the value for the most recent year available.
Source: FAO (2015) *FAO Statistical Pocketbook, World Food and Agriculture*. Reproduced with permission.

Although protein malnutrition is not a healthy condition, a reduced weight for a particular age need not be. Recent studies suggest that children in advanced countries experience a number of allergies and immune system-related problems while those living in underdeveloped countries rarely have food allergies and are more resistant to

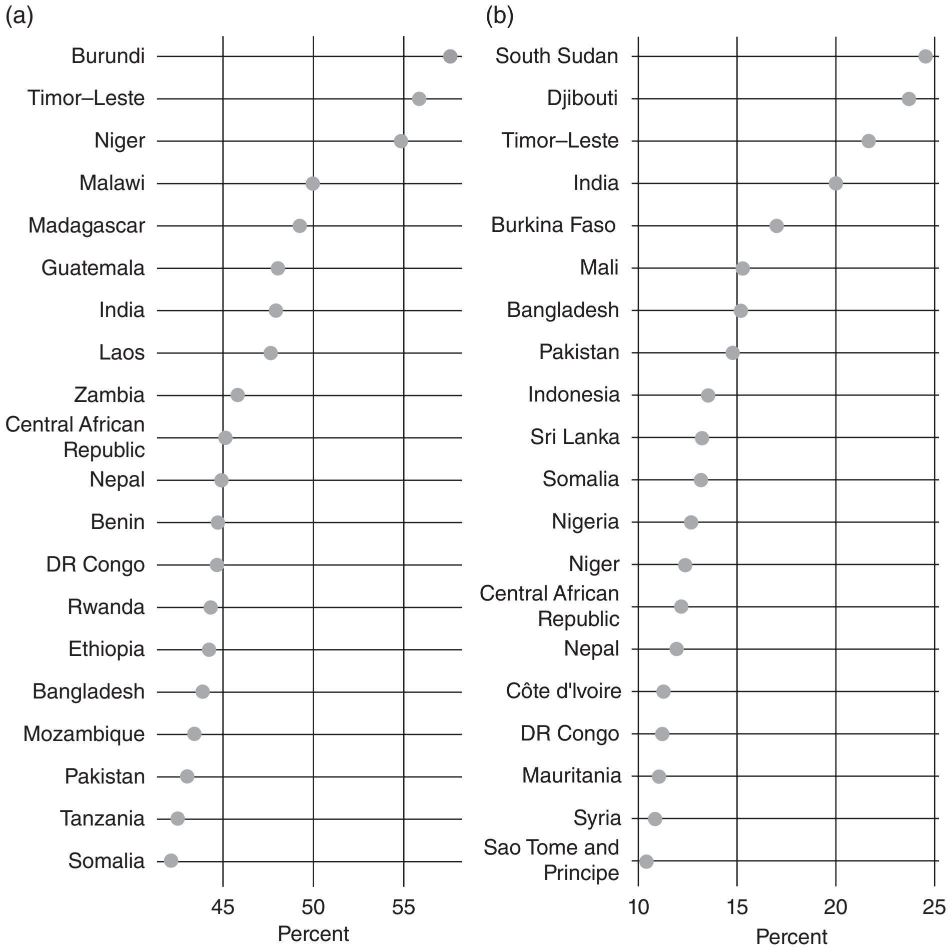

Figure 1.1 (a) Percentage of children under five years who are stunted. (b) Percentage of children under five years who show symptoms of wasting, average data between 2006 and 2014. Both panels represent countries with the highest incidences. The standards for comparison are not clear. By nature, different ethnic groups may possess different physical characteristics. Especially in a society where plant-based meals are prevalent, children may tend to be undernourished. *Source:* FAO (2015) *FAO Statistical Pocketbook, World Food and Agriculture*. Reproduced with permission of FAO.

bacterial infection. In many advanced countries, the issues for children are those associated with being overweight and obese, which may enhance the development of chronic diseases at a later stage in life. Thus the data may not fully reflect the health status of children in these countries.

Figure 1.2 shows an estimate of overall food production (in million tonnes) across different regions and continents. In general, most of the food categories produced, except roots and tubers, are generally low in comparison to the size and population of Africa. Fruit and vegetable production is one of the highest food categories in most regions of the world, accounting for nearly 2 billion tonnes. Of this total, about 800 million tonnes would be wasted assuming average losses of 40%. Preventing the loss of such a considerable portion of fruit and vegetable production through improved postharvest

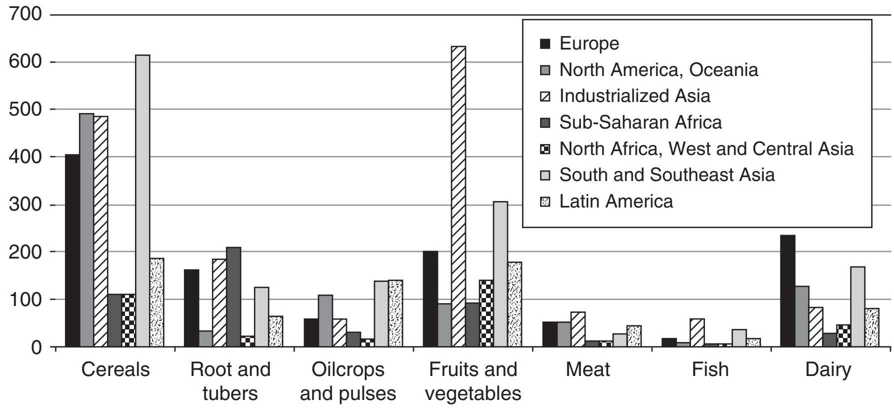

Figure 1.2 Overall production of food (million tonnes) in different regions of the world. *Source:* Reproduced with permission from Gustavsson et al. (2011).

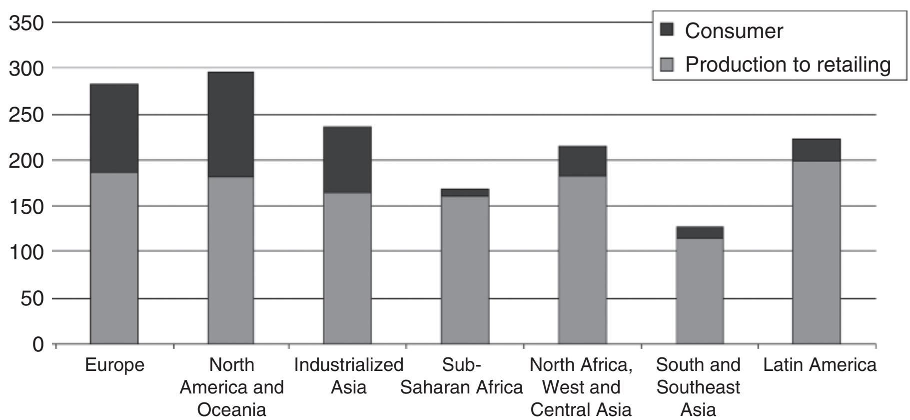

Figure 1.3 Per capita food loss (kg per year) in various regions of the world at various steps in the food value chain, and at the consumer level. *Source:* Reproduced with permission from Gustavsson et al. (2011).

technologies may have a significant impact on increasing food security, both malnutrition and NCD challenges.

Figure 1.3 shows the variation in per capita food loss (kg per year). As shown in the figure, the food loss in North America, Europe, Oceania, and industrialized Asia is in the range of 250–350 kg per person per year, the annual production in these regions being estimated at approximately 900 kg per person per year. The food loss in Africa and South and Southeast Asia is in the range of 100–200 kg per person per year, where the average production is estimated at 460 kg per person per year. Even though production is high in advanced countries, food loss is also higher.

The percentage loss of fruits and vegetables across different steps in the production value chain is shown in Figure 1.4. Most of the loss occurs at the consumer level, processing, and postharvest stages. Consumers waste a large proportion of fruits and vegetables in advanced countries. Most of the losses are at the stages of production,

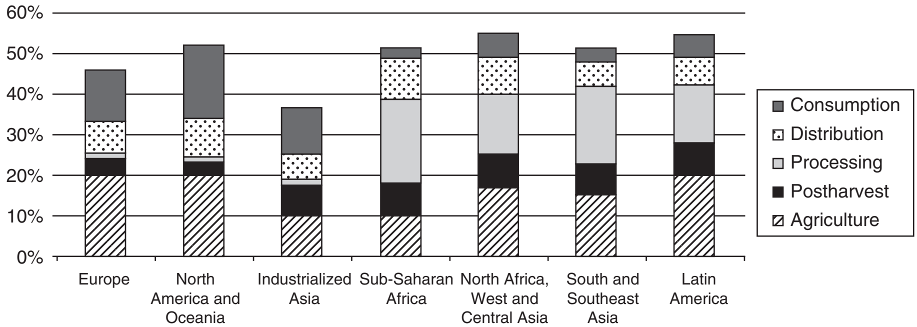

Figure 1.4 Losses in the fruit and vegetable value chain across different segments in various regions of the world. *Source:* Reproduced with permission from Gustavsson et al. (2011).

postharvest, and processing in Africa, Asia, and Latin America. Consumer attitudes must also be changed to reduce the loss of fruits and vegetables.

1.2 Food Security: Changing Paradigms Linked to Food Quality and NCD Challenges

The challenges to global food security have changed and solutions must address both the need to provide sufficient macronutrients and micronutrients to counter the overall malnutrition that exists in several regions of the world and the recent rapid emergence of diet-linked NCDs (Shetty 2014). Therefore, the current strategies for global food and nutritional security must be improved to generate adequate global food production from a wide diversity of crops that will meet macronutrient/micronutrient needs along with beneficial bioactive ingredients to counter diet-linked NCDs (Shetty 2014; Shetty and Sarkar 2018). NCDs present major new costs on healthcare systems worldwide and must be countered with cost-effective solutions based on local food culture and local food ecologies that gave rise to a diversity of ethnic foods with deep cultural significance in diverse geographies (Shetty and Sarkar 2018). At their core NCDs have a metabolic malfunction that leads to increased oxidative stress and reduced microbiome diversity, and improved food production and quality must address this challenge. Therefore, solutions that enhance natural antioxidants and a beneficial microbiome will have substantial impact on NCD prevention and management. In this regard, advancing the health benefits of diverse ethnic foods from a diversity of food crops and associated animal foods in diverse global ecologies may help to counter NCDs, based on a sound ecological foundation that could also be more resilient to climate change challenges (Shetty and Sarkar 2018). Using such a rationale we can advance a systems-based food security solution based on ecological foundations, where control points for solutions are interconnected. These solutions may also be able to address the multiple underlying challenges of food production and quality, from production to processing to design of foods for health, while also addressing environmental challenges of water quality and energy diversification for mitigating global warming (Shetty 2014). The foundations of ethnic foods and their cultural experiences in a target ecology naturally provides a systems-based access to solutions and must be pursued (Shetty and Sarkar 2018).

1.2.1 Population

Food security is directly related to the developmental status, natural and human resources and, to some extent, geographical location. In general, high food security can be expected in countries that are resource-rich and not tarnished by geopolitical issues and a lack of stability in governing systems. The highest proportion of population growth is expected to occur in the developing countries, most located in Africa, and characterized by low income and high economic vulnerability resulting in childhood mortality and poor health, low social stability, and impaired agriculture caused by mismanagement as well as climactic factors resulting from anthropogenic activities. Some countries in Asia, the Caribbean, and the Middle East also fall into this category (Haub 2012). In these countries, population growth is on the order of 2.4% per year, with numbers projected to reach about two billion by 2050. In general, population growth in the Americas and Europe is projected to be minimal, or declining, with the percentage of elderly (>65 years) anticipated to be one of the highest. Thus, the demographic distribution of humans is also changing, all of which may affect the pattern of food supply and use around the world. For example in India, the urban population is projected to be nearly equal to the rural population by 2030. The majority of food supply for the large urban population (~600 million) must come from the rural areas, which involves careful planning to achieve food production, processing, distribution, storage, and delivery systems.

1.2.2 Climate Change and Weather Patterns

Global warming and other added pressures on the food supply are the results of uncontrolled anthropogenic activities, without due consideration to the unified nature of the earth. What happens in one region of the world can have a significant influence on another. With the uncontrolled destruction of rainforests in South America and Asia, which are major buffers for carbon sequestration, the levels of industrial and natural greenhouse gases have steadily increased, creating unusual weather patterns.

Not only is our present course to reduce world hunger unsustainable, our food supply is also being further diminished by global warming, the increased consumption of animals over plants for protein, and increasing conflicts around the world.

Global warming and agriculture are closely linked. When one considers greenhouse gas emissions from land-use change and deforestation, as well as the processing, packaging, transport, and sale of agricultural products, estimates of greenhouse gas emissions from agriculture run as high as 43–57%. On the other hand, agricultural production will be particularly impacted by global warming because high temperatures directly influence crop growth and yields. Because of this complex relationship it is difficult to predict the actual impact of global warming on crop yields, although predictions of yield reductions of 5–50% based on the crop and the geographic region have been made (Molla 2014). Another constraint is that farmers tend to use the same mode of agriculture, using the same cultivars, and these may be unsuited to altered weather patterns. In East Africa, farmers grow corn as a staple food. Traditionally, this was linked to the availability of rain in spring and autumn. Therefore, with the changed rain patterns, the planted corn grows to maturity and when the rain fails all crop is lost (President Kikute of Tanzania, Public speech, 2014). Thus the global change will require farmers to employ a whole new array of agricultural practices and technologies to combat food insecurity in similar regions of Africa.

Global climate change including increased temperatures and altered patterns of weather, resulting in untimely rain, and drought, provides an additional challenge to producing more food (Godfray et al. 2010; Tester and Langridge 2010). Thus, adopting changes to traditional agricultural practices, such as by introducing agroforestry-based production, using fast-maturing varieties of cereals and pulses, using drought-resistant and flood-resistant crops (e.g. rice), and improving storage conditions for harvested food, can overcome many food security issues caused by climate change.

1.2.3 Food, Water, and Energy Security

Food security cannot be separated from water security and energy security, since they go hand in hand for achieving the basic needs of agriculture. In many countries, the availability of water is taken for granted, whereas in semi-arid and arid regions having adequate amounts of water is a luxury. Rainwater is the primary source of water in many regions of the earth, and protecting the excess water from run-off is a necessity for assuring availability of water in lean seasons. In many regions of the world, people use plant sources for energy generation, causing disruption and breakdown by enhancing desertification and affecting food production. In other regions, industrialization and effluent discharge into rivers have made the water toxic, preventing their use for agriculture or drinking. Agroforestry systems are best suited to achieving food and water security, and to an extent energy security. Destruction of forests can adversely affect rainfall and retention of rainwater in the soil. In countries where tropical rainforests have been depleted for cultivation of oil palm, *Eucalyptus* (as a source of timber), tea, coffee, etc., rainwater retention is tremendously reduced.

1.2.4 Choices in Increasing the World's Food Supply

We need to produce more food, preferably with higher nutrients to address both malnutrition and NCD challenges, and also safeguard much of what is produced. Presently, we are investing 95% of our agricultural expenses in the production of food, while investing only 5% in food preservation. The path is clear that we need to invest globally using advanced biotechnological approaches and generate new robust germplasm with improved nutrition and processes for better preservation. Another strategy that is necessary to preserve/safeguard food that is produced is to utilize technologies that help in food preservation and extend keeping quality using genetic, bioprocessing, and better overall technology and machine-based processing.

It should be noted that the global food shortage crisis during the "Green Revolution", in the 1960s and 1970s, led to the development of high-yielding crop varieties, more intensive agricultural practices, and expanded land cultivation. Yields increased substantially in grain crops such as wheat but only marginally in other crops during this green revolution. Agribusiness and government organizations are launching a "Second Green Revolution" in order to produce more food to meet the "Zero Hunger Challenge." Agribusiness sets the agricultural research and education agenda and makes its profits through the sale of seeds, fertilizers, and pesticides (production technologies). It sees little profit in the preservation of food once it is produced. In the absence of agribusiness participation, more pressure is placed on other organizations to mount initiatives to save more of the food that we already produce. The World Food Preservation Center® LLC has met this challenge by launching the "Food Preservation Revolution™."

Many questions have been raised as to whether launching a "Second Green Revolution" is a sustainable approach toward meeting the present world food shortage crisis. The "First Green Revolution," while helping to meet the world's increased demand for food, left in its wake an agricultural system that eventually became unsustainable. It involved significant environmental costs, such as unsustainable groundwater extraction, fertilizer run-off, pesticide residues, and salinization. The First Green Revolution required expensive inputs of fertilizers, pesticides, and irrigation water which were not available to smallholder farmers producing most of the food in developing countries. Since the First Green Revolution, one-third of agricultural land has had to be abandoned because of soil contamination, erosion, and lack of fertility. Also, over 70% of groundwater is used for agriculture globally. In some countries, heavy dependence on irrigation to increase crop yields during the First Green Revolution has resulted in the mining of this groundwater at a much greater rate than it is being replenished.

1.2.5 Saving More of the Food that We Already Produce

One-third of the food that the world produces is lost between the time it is harvested and the time it is consumed. Therefore, saving more of the food that we already produce is a compelling approach. Investments in postharvest infrastructure and research also make good economic sense. Harvested commodities have baked into them substantial investments in the cultivation, harvest, and processing of the crop. Therefore, a tremendous gain can be returned on investments in postharvest infrastructure and technologies. Such investments allow the protection and realization of a full return on investments already made in the production of food. A good example of this is the "Grain Cocoon" technology (commercialized by GrainPro, Inc.). Investments in this postharvest technology allow farmers to realize maximum return on their investment in grain production. In the absence of "Cocoon" technology a 100% loss would have been realized in investments in seed, cultivation, irrigation, pesticides, fertilizers, harvesting, and processing of this grain (Grain Pro).

1.2.6 Nanotechnology in Agriculture and Food

Since the discovery of nanomaterials, several products with potential applications in the agri-food sector have been developed. These include nano-insecticides, and nano-emulsions for growth regulation, packaging materials, and pathogen detection devices based on antibodies, etc. Nanotechnology involves the application of agricultural inputs (fertilizers, insecticides, growth regulators, etc.) in nanometer-sized application or delivery systems in order to enhance the efficiency of application and utilization by the plant target, and to achieve more sustainable practices in agriculture and food areas. At present, agriculture is a highly chemical-intensive practice, primarily caused by the inefficiencies in the utilization and loss of fertilizers into water. By modifying the pattern of delivery and efficacy of agrochemicals through nanotechnology, plant protection, plant growth modification, enhanced stress tolerance, and environmental sustainability of agricultural production practices can be achieved (Subramanian and

Tarafdar, 2011). Postproduction loss of horticultural products can be as high as 50% in developing countries because of inadequate and inefficient storage strategies. Nanotechnology has the potential to enhance the shelf-life, safety, and security of food through appropriate packaging technologies. Appropriate evaluations of safety and efficacy are required before food policies for nanotechnology and its applications in agriculture and food can be established.

1.2.7 Postharvest Technologies

Fruits, vegetables, and flowers are highly perishable entities, and several technologies are employed to enhance shelf-life and quality. Irrespective of the physiology of ripening of fruits (discussed in subsequent chapters), the biochemical methods of ripening-related changes are common, and many technologies are targeted to the regulation of the ripening process, with varying degrees of success (Paliyath et al. 2008). The loss in the fruit and vegetable sector is, invariably, one of the highest, ranging from 40 to 50% in tropical regions. The developing countries experience the largest degree of loss in horticultural produce, affecting both food security and the economic security of people. The oldest of all storage technologies, a simple cold storage system, is still not common in many of the developing countries. Therefore, the problem of postharvest loss has to be addressed at multiple levels.

Regulation of ethylene action is one of the common strategies in postharvest technologies. Employing controlled atmosphere storage has been successful for enhancing the shelf-life of fruits and vegetables. In combination with 1-methylcyclopropene (1-MCP) technology (Lurie and Paliyath 2008), controlled atmosphere storage is a highly successful procedure for storing firm fruits such as apple, pear, etc., over long periods. However, 1-MCP technology comes with some disadvantages, as it inhibits quality of developing biochemical pathways in fruits. Its application in the small-scale operations prevalent in developing countries is difficult. Also, fruits that are consumed soft – most tropical fruits and temperate fruits such as cherry, plum, and peach – are not ideal for treatment with 1-MCP because it inhibits the ripening process. ReTain, another product that claims to enhance the quality of fruit and to prevent fruit fall, is used to some degree in the temperate regions. Other chemicals, such as nitric oxide, ozone, salicylic acid, polyamines, etc., have been explored as a means of enhancing shelf-life and quality in recent years.

A common feature of senescence, irrespective of whether the produce is fruit, vegetable or flower, is the deterioration of the membrane and subsequent loss of membrane compartmentalization. Phospholipase D is the key enzyme initiating this process, and an efficient method of blocking phospholipase D action by hexanal-based compositions is being widely adapted as a common technology (nanocompositions, hexanal vapor) useful for both tropical and temperate produce (Paliyath et al. 2003, 2008; Paliyath and Murr 2007). Field trials of this technology in countries such as India, Sri Lanka, Kenya, Tanzania, Trinidad, Tobago, and Canada have shown multiple benefits. These applications are discussed in detail in the following chapters. Shelf-life extension in the range of three to six weeks has been observed in various fruits. An advantage of this treatment is that treated produce tends to remain in pre-ripening stages when stored at 10–12 °C, and continues to ripen after being returned to ambient temperature (e.g. banana). This flexibility provides an extension of the harvesting window for farmers (by enhancing fruit retention), enhancing the storage window for the packers and shipping agents, and providing an optimum shelf life for consumers. Chapter 20 analyzes the impact of adapting the hexanal-based technologies to mango growers.

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