# Optimizing agricultural practices

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**Chapter Outline**



## 3.1 Introduction

For a long time, insufficient regard was given to food loss and waste, as the major emphasis of agricultural research and development was on crop production and breeding improved cultivars (Snowdon, 2010). However, in recent times interest to reduce food loss and waste has gained momentum. Food losses are not only an important driver of food insecurity in developing countries, but they also represent a gross wastage of the natural resources such as freshwater, cropland, and energy utilized in the production of the lost food (Smil, 2000; Kummu et al., 2012). Food losses are commonly referred as the physical loss of agricultural produce, which was intended for human consumption (i.e., food) along the food value chain (Gustavsson et al., 2011), with an exception to consumption or distribution stages, where the losses are instead termed as food waste. Fewer food losses and waste

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would also mean that there would be reduced pressure on cropland expansion and intensifying agriculture to increase production, which will conserve biodiversity and forests (Sharma and Wightman, 2016). The definitive causes of food losses and wastes vary with specific products and prevailing socioeconomic conditions in each country or location. Past research has revealed that food losses are a significant problem in developing countries due to lack of infrastructure and capacity of the food supply systems, whereas food waste is a phenomenon of the developed world (Hodges et al., 2011; Parfitt et al., 2010; Gustavsson et al., 2011; Kummu et al., 2012). The food loss figures around the world demonstrate a significant spatial and temporal variability, due to the complex and individual characteristics of crop and location. However, general estimates made by the Food and Agricultural Organization of the United Nations (FAO, 2012) suggest that 30% of the global cereal production and 45% of fruits, vegetables, roots, and tubers are lost at harvest and postharvest.

Typical agricultural commodities and product value chain can be broken down into five system boundaries, namely (1) agricultural production, (2) postharvest handling and storage, (3) processing, (4) distribution, and (5) consumption. These agricultural commodities can be further categorized into cereals and pulses, fruits and vegetables, roots and tubers, and livestock and dairy products. Identification of causes and drivers of food losses and waste along these system boundaries and commodities is critical to pinpoint and implement the prevention and reduction solutions and practices (Gustavsson et al., 2011; FLWP, 2016). The agricultural produce is exposed to various postharvest deteriorations, which in a broad sense can be categorized into physiological degradation (due to the natural processes such as climacteric rise in climacteric fruits, etc.), physical damages (increased heat output due to higher respiration, moisture loss, and entry points for microbial infections), chemical injuries (caused by agrochemicals), and pathological decay (infection by fungi and bacteria) (Snowdon, 2010). Hence, the causes of food losses can range from biological, mechanical, to behavioral and organizational issues in a food supply system. Table 3.1 lists some of the common causes and drivers of food losses in production and postharvest systems of agricultural commodities and products particularly in the context of developing countries. In the process of food loss reduction or prevention, the first step is to identify the nature of the deterioration (immediate cause of loss) that is causing rejection or discarding of the food, for example, if there are any microbiological organisms (bacterium, fungus) or insects involved. Secondly, it is required to understand the possible contributory causes (drivers) such as preharvest factors (e.g., weather conditions during production), harvest stage/maturity and method, or postharvest handling and storage.

The focus of this chapter will be to optimize various practices in the agricultural production system boundary (constituting preharvest and harvest subcategories of the food supply system) for *durables* (cereals and pulses) and *perishables* (horticultural products (i.e., fruits and vegetables and roots and tubers), to reduce food losses in developing countries. *Durables* are characterized by high dry matter content, hard texture, and small and homogenous in size.

**Table 3.1** Common food loss causes in agricultural production and postharvest management in developing countries

| **System boundary** | **Agricultural production** | | **Postharvest** | |
|---|---|---|---|---|
| **Subcategory** | **Preharvest** | **Harvest** | **Handling and storage** | **Processing and distribution** |
| Causes and drivers | • Genetic factors<br>◦ Cultivar selection<br>◦ Pest and disease resistant cultivars<br>◦ Reduced physiological disorders<br>• Environment and cultural practices<br>◦ Pest and natural calamity<br>◦ Poor agronomic and cultural practices (soil type, mulching, fertilization, irrigation, pruning and thinning of fruits crops)<br>• Poor market access<br>• Poor organization among producers | • Maturity at harvest<br>◦ Early or delayed harvesting is having an impact on postharvest shelf life.<br>• Harvesting method or technique<br>◦ Physical injuries (mechanical damages)<br>• Lack of on-farm packaging and storage facilities | • Inadequate drying of grains and cereals<br>◦ Temperature and humidity maintenance<br>◦ Curing of roots and tubers<br>• Improper containers and packaging<br>• Improper use of agrochemicals<br>◦ Various treatments (waxing, irradiation, fumigation, fungicide treatments, ethylene)<br>• Inadequate information and knowledge on proper postharvest practices.<br>• Poor roads, transportation, and market access<br>• Lack or poor storage conditions and facilities | • Lack or inadequate processing facilities<br>• Inadequate processing capacities<br>• Delays in distribution<br>• Poor storage conditions during distribution<br>• Inappropriate packaging |

*Perishables*, on the contrary, have a higher moisture content (MC), soft texture, and large and irregular shape and size (making them susceptible to desiccation (wilting, shriveling) and mechanical injury during harvest and handling) (Rees, 2012; Kader, 2013). Pest and disease are the major concern for the *durables*, whereas maintenance of physiological processes (internal processes such as respiration and ethylene production) is crucial in case of *perishables*. Grains such as wheat, rice, and maize are primary staples around the globe providing the major part of the calorie intake, however in various parts of the world other crops like cooking banana in East Africa, breadfruit in the South Pacific Islands, yams and cassava in West Africa, and potatoes in South America are important staples (Snowdon, 2010). Moreover, legumes and pulses are important sources of protein in various parts of the world (e.g., in India), whereas fruits and vegetables provide essential vitamins and minerals for a balanced diet. Apart from food, horticultural products contribute significantly to the economies of various countries regarding exports.

Several variables in the agricultural production stage (before farm gate or at farm gate, Table 3.1) determine the extent of food losses, for example, method of harvesting, variety of the crop, timing of the harvest (ripeness of the grains or fruits) (Smil, 2000; Brasil and Siddiqui, 2018). Hodges et al. (2011) stated in a review of food losses from developed and developing countries that it is critical for the developing countries to look before farm gate to reduce food losses. Some of the critical drivers mentioned in this review were educating farmers on postharvest management and causes of food losses, improved infrastructure to access markets, emphasis on building smallholder organizations, and access to postharvest technology investment microcredits. The World Bank (2011) in a report on "missing food" reiterated that most of the food losses in developing countries occur near to the farm, where the choices of crop, cultivar, harvesting technique and initial handling are made. Siddiqui (2018) restated that among all the factors responsible for the overall postharvest quality of the perishable products (especially fruits and vegetables), more than 70% lies in the preharvest and harvesting conditions. For example, for roots and tubers globally about 20% of the product is lost at agricultural production stage (Gustavsson et al., 2011), whereas close to 6% of the cereals are lost in African countries in agricultural production stage during harvest and field drying. African postharvest loss information systems (APHLIS, 2017) recorded losses (dry weight basis) for wheat, maize, rice, sorghum, and barley of about 3.5%, 6.2%, 4.4%, 4.4%, and 3.5% respectively during harvesting and field drying.

It is known that overall state and quality of agricultural products (both perishables and durables) cannot be further improved once harvested, which depends on the producer's choices of crop species, cultivar (or variety), time of planting, and following cultural and harvest practices. Moreover, market factors were also considered as one of the preharvest factor affecting postharvest gains or losses; the market has a significant influence (when the majority of the crop is intended for sale) on the producer's decisions and the required quality criterion for the intended consumers (Simson and Straus, 2010).

## 3.2 Preharvest systems

Preharvest practices and treatments play a key role in enhancing the quality and shelf life of the agricultural products (Sidiqqui, 2018). In the postharvest phase, one is only limited to keeping the quality obtained at harvest by decreasing the rate of deterioration but this does not necessarily improve on what has already been harvested. Some of the important preharvest factors that influence the postharvest quality (sensory and keeping/shelf life) are variety (genetic/cultivar), climatic (or weather) conditions, irrigation (water supply), soil fertility, fertilizer application, use of agrochemicals, and last but not the least insect pest and diseases (FAO, 1989; Fallik, 2008; Snowdon, 2010). These factors can also be categorized into *abiotic* and *biotic* stresses (Kays, 1999; Kader, 2000; El-Ramady et al., 2015). The typical *abiotic* stresses are water stress (deficit or access), temperature (too hot or too cold), and soil salinity. Whereas, *biotic* stress would be the stress caused by other living organisms such as bacteria, fungi, virus, parasites, and weeds. Examples of various preharvest factors affecting postharvest quality are listed in Table 3.2. Sams (1999) in a similar review listed several examples of how various abiotic and biotic factors would affect the texture of horticultural products. Texture traits (defined as a feeling of touch, deformation, disintegration, and flow, which can be measured objectively with a function of force, time, and distance) are very important in determining the market acceptability. The textural properties could also relate to mechanical, geometrical, and chemical characteristics, for example, hardness, shape, and MC respectively. The products of poor texture may be rejected at one or the other stage of the value chain resulting in significant food losses and wastes. The texture is particularly influenced by changes in cell organelles and biochemistry, MC, and composition of the cell wall. Any of the biotic or abiotic factors affecting these properties can change the texture leading to the changes in the product quality.

Physical injuries are a major problem in almost all the agricultural products from cereals and grains to fruits and vegetables. However, the extent and impact of this problem are much more in the horticultural sector. One of the most common types of injuries is bruise damage, which can occur in preharvest, harvest, handling, and transportation stages, and are known to cause considerable economic and physical losses along the product value chain. Hussein et al. (2018), lists various genotypic, environmental, seasonal, and management related factors during the production of the horticultural crops, which significantly affects the postharvest susceptibility to injuries like bruises.

### 3.2.1 Cultivar and environment

Every agricultural commodity has a range of genotypic variations in composition, quality, and postharvest shelf life potential (Kader, 2000). Classical/traditional breeding and modern-day molecular based genetic manipulation have the potential to maintain flavor and nutritional qualities and the introduction of resistance to

**Table 3.2** The broad category of preharvest factors affecting the postharvest quality of agricultural produce

| Factors | Type of causes | Examples |
|---|---|---|
| Biological | Pathological, entomological, animal | • Bacterial spot on tomato fruit.<br>• Fungal—white mold on the blossom end of cucurbits<br>• Virus—zucchini yellow mosaic virus of squash<br>• Nematodes—northern root-knot nematode<br>• Cabbage loopers (*Trichoplusia ni Hüber*)<br>• Tomato horn<br>• Worms (*Manduca* spp.)<br>• Flower thrips (*Frankliniella occidentalis* Pergande)<br>• Sweet potato weevil (*Cylas* spp.) |
| Physiological | Physiological disorders, nutritional imbalance | • Tomato blossom-end rot (a calcium deficiency related problem)<br>• Cracking in tomato and cherry fruit is a nutrition and water-related problem<br>• Nitrogen deficiency in leafy vegetables<br>• High nitrogen is resulting in poor coloration in apple, cranberry |
| Environmental/ cultural factors | Climate, weather, soils, water relations, light intensity | • Chilling injuries<br>• Freezing/frost damage<br>• High-temperature stress<br>• Wind damage<br>• Soil textural properties (for root crops) |
| Extraneous matter | Growing medium, vegetable matter, chemical residues | • Ions of heavy metals, (Ag, Cd, Co, Mg, Mn, Ni, and Zn)<br>• Ozone causes surface blistering of spinach (*Spinacia oleracea* L.) leaves |
| Genetic variations | Cultivar tolerance to pest and disease, physiological stress, and injuries (physicomechanical properties) | • Shape, size, and color<br>• Desired phenotype<br>• Heterozygous |

Source: Adapted from Kays, S.J., 1999. Preharvest factors affecting appearance.pdf. Postharvest Biol. Technol., 15 (June 1998), 233–247. http://dx.doi.org/10.1016/S0925-5214(98)00088-X; Sams, C.E., 1999. Preharvest factors affecting postharvest texture. Postharvest Biol. Technol., 15 (3), 249–254. https://doi.org/10.1016/S0925-5214(98)00098-2; Mattheis, J.P., Fellman, J.K., 1999. Preharvest factors influencing flavor of fresh fruit and vegetables. Postharvest Biol. Technol. 15 (3), 227–232. https://doi.org/10.1016/S0925-5214(98)00087-8; Hussein et al., 2018.

postharvest physiological disorder and pests and diseases. Farmers and development agents must consider the choice of the right varieties for a particular location and target markets. Use of cultivars, resistant to disease and pest, having a longer postharvest shelf life and integrated crop management systems can maximize the yields and quality of the product at harvest (Kader, 2013). FAO (1989) gave an example of mangoes in Indonesia where 242 mango varieties are available, but only 7 of them have commercial potential. Hence local growers shall choose what cultivar they want to grow to enhance their income. For example, cultivars with thicker skin and firm texture (particularly for fresh fruits and vegetables) tend to have a longer shelf life (Snowdon, 2010).

Environmental or climatic variations (climatic conditions) are the second most important factor after cultivar determining the flavor and ratio of different constituents of various fruits and vegetables. For example, acid and sugar ratio, and pungency were significantly affected by season in tangerine (*Camellia reticulata*), grapefruit (*Citrus paradise*), and onions respectively (Mattheis and Fellman, 1999). Excessive exposure to sunlight (light above the photosynthetic saturation) can increase the temperature of the fruit resulting in damage and loss of firmness; an example of such damage is sunscald, which is common in apples and tomatoes (Sams, 1999). Due to higher tissue density, firmness of most nonchilling sensitive fruits is higher at low temperatures.

### 3.2.2 Integrated pest and disease management

Pest control protocols need to be implemented and followed along the entire food value chain to ensure efficient control. Use of clean (disease and pest free) planting material (true seeds, seed tubers, and cuttings) is a prerequisite to control disease in the field and postharvest. For example, onion seeds are very often infected with molds (Snowdon, 2010), requiring a preplanting fungicide treatment. Establishing seed certification schemes for important crops in the developing countries is critical to obtain healthy planting material in preharvest for better postharvest quality and shelf life. Reducing mycotoxigenic fungi load during postharvest stages of various crops (not only for cereals and nuts/peanuts but also apples and grapes) has emerged as a global challenge. Some of the most potent mycotoxigenic plant pathogens are *Fusarium*, *Aspergillus*, and *Penicillium* spp. One of the potential solutions for this problem is mycoparasitism where the preharvest application of beneficial fungi such as filamentous fungi and yeasts is incorporated (Sarrocco and Vannacci, 2017) to reduce the infection of pathogenic fungi. Recovering and reimplementing the indigenous knowledge in reducing the losses at farm due to insect and pests is critical, particularly in the developing world where landholdings are small, and cost of modern pesticides and insecticides are high. Sharma and Wightman (2016), quoted a wonderful example where scientists tested indigenous knowledge (shakedown approach following with hen who feeds on the larvae) to control pod-borers in pigeon pea, and the results were fantastic; the simple shakedown approach reduced the losses by 85%. In a recent survey Parmar et al. (2017a), along with various other prospective control measures to reduce sweet potato postharvest losses in

**Figure 3.1** Sweet potato weevil (*Cylas puncticollis* and *Chorthippus brunneus*) damaged root at harvest in southern Ethiopia.
Source: Picture by Aditya Parmar.

Ethiopia, mentioned the preharvest practices such as using early maturing and deep-rooted varieties, crop rotation, clean planting material, sex pheromone traps, and hilling-up as some of the measures to control sweet potato weevil, which is a major production and postproduction problem in East Africa. A picture of a sweet potato weevil−damaged root is presented in Fig. 3.1.

### 3.2.3 Diversifying the crop production

Researchers at the Royal Botanical Garden have estimated that close to 200,000 plant species are edible and safe for human consumption out of more than 400,000 presently alive plants on Earth. Given this vast number of plant species available for human consumption, the current human diet is highly conservative; we rely on fewer than 150 plant species for our food supply, and close to three quarters of the global grain market comprises of wheat, rice, maize, and barley (Sharma and Wightman, 2016; Charrondiére et al., 2013). Presently 95% of the global carbohydrates supply is provided by a mere 30 species, which has significant impact not only biodiversity, food losses, plant disease, and pest infestation but also on human nutrition and health (WHO, 2015; Charrondiére et al., 2013). Rosner (2014) mentioned that about 18,000 legume species are available around the world; these species are nutritious, resistant to pest, diseases and adverse climate and weather conditions, yet fewer than 50 are domesticated for human food. Some of the examples of these underutilized legumes are potato beans (*Apios americana*), Marama beans (*Tylosema esculentum*), Yehub nut (*Cordeauxia edulis*), and beans of genus *Lupinus*. Diversifying the crop mix in agricultural systems of the developing countries can be one of the coping strategies against food insecurity and can enable smallholders to harvest at maturity (Hodges et al., 2011). For example, resource poor smallholders in low-income countries may harvest their crops prematurely, due to food shortage or urgent need for cash, particularly around the second half of the agricultural season. This premature harvesting results in loss of nutrition, financial value, and unsuitability for processing or certain consumptions (Gustavsson et al., 2011). One way to avoid such a situation and associated food loss is by diversifying the production of resource poor smallholders into a variety of cash crops and animal products. By this way they are also more likely to obtain credits from microfinancing institutions or advances from wholesalers or processors (Gustavsson et al., 2011). The crop diversification not only leads to lower chances of food waste at farm and market but also leads to a more nutritious diet for the community. In recent times there has been a significant thrust on improving the diversity of human diets, as it is a common belief among natural scientists that intensive industrial agriculture is not sustainable and does not lead to a healthy human diet (Dwivedi et al., 2017). In a mega study from 150 countries Khoury et al. (2014) highlighted that total crop diversity has shrunken significantly in the last 50 years, and diets have become more homogeneous (depending on the regionally important crops). Such a finding put additional pressure on diversifying farm production and providing market access to a host of diversified crops, particularly on the smallholder subsistence farmers (Dwivedi et al., 2017). Another indicator of global loss of crop diversity is the production data from FAOSTAT (2015), which shows that from 1961 to 2013 land area cultivated for wheat, rice, and maize has increased up to 79%, whereas for barley, millet, oats, rye, sorghum it has reduced by 19% to 33%.

### 3.2.4 Improved agronomic and cultural practices

Appropriate agronomic and cultural practices ensure the produced agricultural commodity is of higher quality, which reduces losses from rejections and discards along the value chain. Various abiotic and biotic stresses in preharvest can have a negative impact on the quality of the produce postharvest. For example, preharvest water stress can affect quality and shelf life of the product postharvest. Water stress during production is known to be connected with higher weight loss during postharvest storage in various fruits and vegetables (El-Ramady et al., 2015). Another important factor related to the quality of the fruits and vegetables is moisture or water loss in (pre- and postharvest stages of the food supply chain), a water loss of as little as 3%−5% can reduce the marketability of many leafy vegetables and fruits. Plant nutritional factors during the growth and maturation stages have again a significant effect on the postharvest quality. Some of the more important nutrients that fall into this category are nitrogen, phosphorus, and potassium (NPK) and calcium (Ca). Applying more than the recommended amount of nitrogen fertilizer preharvest can result in discoloration of cabbage (due to high accumulation of Zn and Al and deficiency of Mn) and potato (black spots due to bruising) during postharvest storage (El-Ramady et al., 2015). Moreover, excess N and P are known to decrease firmness in many crops (Sams, 1999). Ca is another element that is directly related to fruit and vegetable firmness and textural properties as it is essential to strengthen the plant organ cell wall, which is very important from a postharvest point of view. Soil that is deficient in Ca and K resulting in deficiencies in fruits and vegetable is linked to various postharvest disorders (Kader, 2000). In some cases, preharvest sprays of Ca on fruits and vegetables are required to improve the postharvest shelf life and rigidity of these products to mechanical injuries during postharvest handling.

Some of the important aspects of good cultivation practices that are essential for improved quantity and quality of the fresh produce are better weed control (which competes with crops for nutrient and water) and crop hygiene or sanitation in terms of using clean planting material and removing potential source of infections such as infected parts of the crop from previous harvest before planting new crop. Nowadays, use of agrochemicals (pesticides, herbicides, and growth regulators) are common in most of the production systems around the world, and care must be taken in their use as overuse and choosing inappropriate chemicals for weed and pest control can affect the physical (e.g., spray-burns), sensory, and safety quality (toxic residues) of the product (Snowdon, 2010; Simson and Straus, 2010). For certain roots crops (potato, cassava, sweet ptoato), dehaulming or canopy removal a few days before harvest can lead to improved skin-setting resulting in reduced moisture loss and injuries during postharvest handling and transportation. Parmar et al. (2017b), through an empirical study, demonstrated how preharvest dehaulming (sometimes called as preharvest curing) of sweet potatoes in southern Ethiopia resulted in enhanced skin strength or adhesion.

## 3.3 Harvest systems

The harvest is the operation of collecting the mature, useful, or economic part of the plant from the fields (Simson and Straus, 2010). In developing countries where the majority of the crop production is done by smallholders on small farms mechanization is limited (due to economies of scale issues), and harvesting time of the crop cultivation is the most labor incentive activity. Bad or extreme weather conditions during harvesting (e.g., frost, rain, storm, and unusually warm or cold conditions) can affect the quality and yields of the crop. Hence, the timing and an unlikely weather event can be damaging for the mature crop ready to be harvested.

The harvest of the crop is one of the most crucial transitions of the agricultural commodities. This transition is much more stressful for perishables (horticultural crops) rather than durable crops such as cereals and grains. Good harvesting practices and knowledge of proper harvest maturity indices is critical for ensuring longer postharvest shelf life and improved quality of the product. Moreover, scheduling of harvesting times with target markets can improve the income of the smallholders and reduce the losses due to oversupply (market gluts). Maturity, internal characteristics at harvest, stage, and proper method of harvesting help retain the quality of horticultural produce and reduce postharvest losses (Prasad et al., 2018).

### 3.3.1 Harvest and handling techniques

Harvesting technique can be subdivided into two broad categories (Fig. 3.2): complete hand harvesting, and mechanical or mechanical assisted harvesting (which is a combination of manual and machine, e.g., loosening of soil in case of root crops with a mechanical digger and manual collection of roots). In general, it can be said that hand harvesting may result in the harvest of more undamaged and horticultural matured fruits and vegetables. However, it may depend on the training, management, and contractual arrangement with the involved manual labor. Experience from past studies has shown that when the contractual agreements are short-term and based on per box or sack, or per hectare; there is lack of teamwork; working hours are long without breaks; weather conditions are bad; and laborers lack training; this can result in careless harvesting, causing significant mechanical injuries and poor quality of horticultural commodities (Simson and Straus, 2010).

For fruits and vegetables especially, harvesting should take place during the coldest time of the day (early morning), and the product should be placed in the shade immediately to avoid direct sunlight (especially in tropical conditions). Moreover, the harvested crop should have minimum levels of physical damage (skinning, bruising, cuts, and breakages), mainly when the commodity has to travel to a distant market or needs to be stored for a longer duration. El-Ramady et al. (2015) and Sharma and Singh (2012) distinguished the mechanical injuries (or lesions) for horticultural crops into two broader types:

*Cuts and punctures*: Loss of tissue integrity, surface injuries. Such injuries can lead to increased rates of respiration and ethylene evolution leading to a rapid deterioration of the product, whereas they are mostly caused by harvesting tools. The product becomes vulnerable to pathogen infections, most predominantly rotting

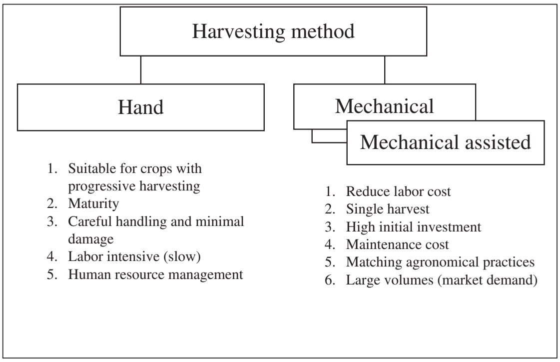


**Figure 3.2** Harvesting methods.
Source: Adapted from Sharma, R.M., Singh, R.R., 2012. Harvesting, postharvest handling and physiology of fruits and vegetables. In: Verma, L.R., Joshi, V.K. (Eds.), Postharvest Technology of Fruits and Vegetables (fourth ed.). Indus Publishing Company, New Delhi, pp. 1−484.

fungi and bacteria. An example of cuts and punctures is demonstrated in Fig. 3.1, where harvesting tool−associated cuts and punctures in sweet potato are shown.

*Bruises (Impact, compression, abrasion injuries)*: Such injuries may depend on maturity, water potential, tissue firmness, and temperature of the product. They are subsurface, which may only be detected several days after when the product has already reached the final consumer.

Moreover, during harvest or immediately after presorting, removal of inedible parts such as leaves and folios and packaging takes places to prepare the product for market. During these activities (handling) the fresh horticultural produce can sustain various injuries resulting in a cumulative effect on the marketability and shelf-life of the product (Simson and Straus, 2010).

Harvesting tools and containers (particularly for horticultural products) play an important role in reducing the extent and number of these injuries. Care must be taken in choosing an appropriate container for harvesting to avoid injuries and contamination of the freshly harvested product. Fig. 3.3 provides an example of sweet potato roots being extremely vulnerable to rotting if they are damaged during harvesting and handling. As for the time of the day when the harvest should take place,


**Figure 3.3** Cuts and punctures (A, B) in sweet potato induced by harvesting tool. Vascular browning or mottle necrosis (C) caused by *Phytophthora rot* (*Phytophthora* sp.) in damaged root 2 weeks after harvest.
Source: Picture by Aditya Parmar.

this should be during cool morning hours, as firmness is higher during cool periods and less energy is required for precooling (Simson and Straus, 2010). Keeping the freshly harvested horticultural product in the shade, protecting it from direct sunlight in tropical climates is important. Lastly, training of the harvest labor is the most important factor; the training should focus on how to handle the product gently and with care, and we aware of the postharvest losses that may be caused by injuries induced during harvest and handling.

### 3.3.2 Harvesting maturity

Harvesting at optimum maturity is critical to determine the final consumer quality of the horticultural products; immature fruits may sustain shriveling, internal and external injuries and poor sensory attributes, whereas overly matured may become too soft, mealy, and insipid before reaching the consumer (Fallik, 2008; Simson and Straus, 2010). The maturity of the agricultural commodities (fruits and vegetables) can be categorized into two types:

*Physiological maturity*: When translocation of photosynthates stops, and no further increase in dry matter content of the product. For fruits and vegetables, it is the stage of development when these plant parts continue to ripen after harvest.

*Horticultural (or commercial) maturity*: When the product is harvested at a stage for a specific purpose, for example, for storage or prerequisite usage such as processing into juice.

All agricultural produce may show one or more distinguishable signs or characteristics of its physiological (or biological) maturity. Tomatoes, for example, at physiological maturity, fill their internal locules with gelatinous mass, and when the matured fruit is cut with a sharp knife seeds remains intact (Simson and Straus, 2010). However, the physiological maturity may not always coincide with commercial or horticultural maturity, which is important from a transportation and market point of view. Delayed or too early harvest of agricultural commodities can limit the shelf life and economic value of the product. The maturity of the produce at harvest is one of the most important factors that defines the postharvest shelf life and quality (e.g., regarding appearance, aroma, texture, flavor, nutrition). Harvesting at proper or appropriate maturity (depending on the specific crop and end consumer use) can facilitate more efficient packaging, transportation, and distribution (El-Ramady et al., 2015).

All agricultural produce (grains/seeds, fruits, vegetable, roots and tubers) is the living organs of the plant, which are metabolically active, undergoing respiration (carbohydrates such as starch and sugars are degraded in the presence of oxygen are converted into carbon dioxide, water and energy), ripening, and senescence (for fruits and vegetables). The generic equation for aerobic respiration is presented in Eq. (3.1). The rate of respiration (mL $CO_2$/kg · h) would depend on the ambient temperature and nature of the product.

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + \text{heat} \tag{3.1}$$

To calculate heat production multiply mL $CO_2$/kg · h by 440 to get Btu/ton/day or by 122 to get kcal/metric ton/day (UCDAVIS, 2018).

Fruits, depending on their biological control of ripening [the production of ripening hormone ethylene ($C_2H_4$)] and respiratory rates, can be classified into two groups (Rees, 2012; Sharma and Singh, 2012; Prasad et al., 2018):

*Climacteric*: The fruits belonging to this category possess autonomous ripening behavior (when harvested as physiological mature but not ripe or horticulturally mature), meaning they are capable of developing changes in taste, aroma, color, and texture after being detached from the mother plant. The ripening is associated with increased rate of respiration (also known as climacteric rise) and production of ripening hormone ethylene. Examples of climacteric fruits are apple, avocado, mango, banana, papaya, peach, tomato, etc.

*Nonclimacteric*: The fruits are incapable (or have the very limited ability) of developing a horticultural maturity after harvest. They do not show an increase in respiration and ethylene production rates, but a constant decline during the ripening process. Examples of nonclimacteric fruits are cherry, grape, lemon, lychee, mandarin, pineapple, strawberry, watermelon, etc.

Hence, the climacteric fruits can be harvested at their physiological maturity for the distant markets as the transportation time can be utilized to achieve horticultural maturity. However, it is more problematic for nonclimacteric fruits where horticultural and physiological maturity are very close, and requiring rapid transportation and better cold chain conditions to reduce losses.

Management of these metabolic and physiological processes at harvest and postharvest is crucial to reduce physical and nutritional losses along the value chain. Postharvest environmental conditions (temperature and humidity in particular) have a major impact on the quantitative (physical) and qualitative (nutritional) losses (Brasil and Siddiqui, 2018). For example, in case of fruits and vegetables, an increase of 10°C in the storage temperature could double, triple, or quadruple the rates of the respiration leading to weight and nutrient loss (Snowdon, 2010). Moreover, for grains and cereals, apart from temperature, MC (or water activity) can play an important role in determining the respiration rates (Coleman et al., 1928; Raudienė et al., 2017). For example, Huang et al. (2013) reported that the respiration rate of corn (maize) increased 100 times when the MC of the corn increased from 14% to 22%. Whereas the reparation rates doubled with every 10°C increase in the ambient temperatures. Raudienė et al. (2017) recorded that the respiration rates of wheat increased from approximately 5 mg $CO_2$/kg/h with 13% MC and 20°C ambient temperature to 30 mg $CO_2$/kg/h for 19% MC, and at higher temperatures the respiration rates of wheat showed increment; the increment was starker when the wheat had higher MC. A similar increase in rice and soybean respiration rates with increased MC and ambient temperatures has been reported by Dillahunty et al. (2000) and Sorour and Uchino (2004) respectively. This is a typical problem in tropical countries where ambient temperatures are high; the problem is further compounded due to lack of money to provide controlled atmospheric storage and transportation facilities. Therefore, cost-effective technical innovations to reduce food losses in developing countries are one of the major focuses of postharvest research and development. The respiration rate is the main factor determining the shelf life (or perishability) of the agricultural produce. Table 3.3 provides the respiration rates of some of the important cereals, fruits, and vegetables.

In cereals and grain, harvest takes place in general after 10–15 days of attaining physiological maturity. Moreover, the MC is the most important indicator for harvest maturity, for much of cereals crops, optimum MC (percentage-wet basis) at harvest shall range from 10% to 23%. Providing specific examples, for example, wheat shall be harvested at 16%–18% MC, paddy at 20%–22%, maize at 20%–23%, and groundnuts at 10%–12%. For storage of these cereals, they need to be

**Table 3.3** Respiration rates of various agricultural product groups

| Agricultural product group | Respiration rate (mL $CO_2$/kg · h) at 20°C | Rate of ethylene (μL C2H4/kg · h) production at 20°C |
|---|---|---|
| **Durables**[a] | | |
| Wheat, 13% MC, 20°C (Raudienė et al., 2017)<br>Rice, 15% MC, 20°C (Dillahunty et al., 2000)<br>Soybean, 14% MC, 20°C (Sorour and Uchino, 2004)<br>Corn, 14% MC, 20°C (Huang et al., 2013) | ~5 mg $CO_2$/kg/h<br>>1 mg $CO_2$/kg-h<br>>1 mg $CO_2$/kg dry matter.h<br>0.31 mg $CO_2$/kg/h | –<br>–<br>–<br>– |
| **Semiperishables (roots and tubers) (UCDAVIS, 2018)** | | |
| Potato<br>Sweet potato<br>Onion<br>Jicama<br>*Perishables* | 9–23<br>27–35<br>27–29<br>3–4 | Very low<br>< 0.1<br>–<br>Very low |
| **Climacteric [lower value for preclimacteric and higher for climacteric peak] (UCDAVIS, 2018)** | | |
| Apple (red delicious)<br>Avocado<br>Banana<br>Breadfruit<br>Mango | 12–25<br>40–150<br>20–70<br>38–178<br>35–80 | 20–125<br>>100<br>0.3–10<br>0.1–1.6<br>0.5–8 |
| **Nonclimacteric (UCDAVIS, 2018)** | | |
| Grapes<br>Grapefruit<br>Lychee | 12–15<br>7–12<br>25–40<br>15–20 | –<br><0.1<br><0.5<br><0.2 |

*MC*, moisture content.
[a]The respiration rate for cereals and grains would depend significantly on the MC of the grain seeds and the ambient temperature.

dried further postharvest to attain option storage MC that in most cases lies between 10% and 12% (Sahay and Singh, 2016). It is always recommended to use several maturity indices as environmental factors can influence individual maturity indices so that no mistake in harvesting time is made and the crop is always harvested at its optimum desired quality and postharvest life.

Assessment of maturity at harvest is a problem for both climacteric and nonclimacteric fruits (Table 3.4). Climacteric fruits, if harvested at an immature stage, may not ripen properly, and if harvested at an advanced stage of maturity may

**Table 3.4** Various harvest maturity indices

| Methods | Indices | |
|---|---|---|
| | **Fruits and vegetables (horticultural crops)** | **Cereals and pulses (grains)** |
| Computational | 1. Calendar date<br>2. Days from full bloom<br>3. Mean heat units<br>4. T-stage | 1. Days after flowering (*anthesis*)<br>2. Mean heat units |
| Physical | 1. Fruit retention strength<br>2. Fruit size and surface morphology<br>3. Weight<br>4. Specific gravity<br>5. Color<br>6. Firmness<br>7. TSS | 1. Color of the glumes, peduncle and pods (e.g., yellowing of the leaves, pods turning brown, stems turn to straw color)<br>2. Drying of the pods, ears, leaves, or other parts of the crop<br>3. Kernel hardness<br>4. Seed development<br>5. Shedding of lower older leaves |
| Chemical | 1. Titratable acidity<br>2. TSS/acid ratio<br>3. Sugar content (Brix readings)<br>4. Sugar/acid ratio<br>5. Bioelectric conductance<br>6. Starch content<br>7. Starch-iodine test<br>8. Tannin content<br>9. Juice or oil content | 1. Moisture or dry matter content<br>2. Oil content (e.g., in oil crops)<br>3. Starch content<br>4. Sugar content |
| Physiological | 1. Respiration rate<br>2. Ethylene evolution rate | 1. Photosynthesis assimilates supply stops (no more increase in dry matter content)<br>2. Seed black layer and milk line development (for maize)<br>3. Hard dough stage |

*TSS*, Total soluble solids.

Source: Adapted from Sharma, R.M., Singh, R.R., 2012. Harvesting, postharvest handling and physiology of fruits and vegetables. In: Verma, L.R., Joshi, V.K. (Eds.), Postharvest Technology of Fruits and Vegetables (fourth ed.). Indus Publishing Company, New Delhi, pp. 1−484 and Sahay, K.M., Sing, K., 2016. Unit Operations of Agricultural Processing. Vikas Publishing House Pvt Ltd., Noida, India.

already reach its climacteric peak in the transitory period before it is consumed. As after the climacteric peak, the rate of respiration declines and senescence and decay of the product quality initiates. Moreover, the problem is more complex in the case of nonclimacteric fruits, which do not undergo a ripening process when detached from the plant. Whereas vegetables (e.g., green leafy ones) start to decay as soon as they are harvested; the most prominent physiological process in these vegetables is the loss of chlorophyll (senescence resulting in the yellowing of the tissue) (Snowdon, 2010).

For practical purposes at the farm level, commercial and smallholder farmers employ color and degree of developing as the two most common indices to determine harvest time. In certain commercial or industrial farming days from flowering and accumulation of heat, units may be calculated to determine optimum maturity time.

## 3.4 On-farm postharvest systems

Postharvest handling takes place at the stage of crop production immediately after harvest. The typical steps in a postharvest operation may include cooling and sorting of horticultural crops and drying and on-farm storage of the cereals. The harvest (the useful part of the plant) is the living organs or seeds of the plant, which continue to respire and metabolize. The focus of this chapter is on the optimization of the handling and storage practices on the farm to reduce on-farm losses, which are a major concern in developing countries. As soon as the crop is uprooted from the ground or detached from the mother plant, it starts to deteriorate. The postharvest management of the crop will ultimately decide if the product would finally reach in its intended quality (or harvest quality) to the final consumer or not. Hence, the initial few hours or days after harvest are critical for defining the shelf life or long-term storage potential of a crop.

For certain roots and tubers (such as cassava, garlic, potato, onions, sweet potato, and yams) immediate postharvest curing (in most cases at the farm, for 3 up to 7 days) may be essential to improve postharvest shelf life and overall quality of the product. The drying out and thickening of skin tissue as a barrier to moisture loss and pathogenic infections are the primary goals of curing. In the bulb crops such as onions and garlic, the outer shell or scalers are dried to ensure longer shelf life. Whereas for potatoes and sweet potatoes wound healing and skin setting (lignification of periderm) to reduce skinning and bruising injuries during successive handling and storage is attained. In most of the cases curing required hot and humid conditions (with good ventilation) ranging from 15°C–20°C to 30°C–32°C and 85%–90% Relative Humidity (RH) for potatoes and sweet potatoes, and 32°C–40°C and 90%–100% RH for tropical roots and tubers such as cassava and yams. Whereas, bulb crops like onions and garlic may be cured 33°C–45°C at 60%–75% RH.

For smallholders in developing countries where controlled atmospheric curing chambers may not be available due to economic reasons, curing of crops like yams, sweet potato, and cassava can be obtained by piling the roots and tubers in the shade (heaping under a tree for example) and covering them with straw and grass to increase relative humidity, the tropical temperatures may be just enough to get the desired results.

In postharvest, temperature and humidity are the two most important factors that influence the decay and deterioration of the horticultural commodities (perishables, fruits and vegetables, and roots and tubers). Heat injuries, particularly in the tropical environments, can be harmful to perishable products causing localized necrosis in the form of sunscalds and general decay. Every commodity has an optimum condition at which it will maintain quality and improved shelf life. When not stored in option temperature and humidity decay rate may increase two to three times for every 10°C increase in the temperature (Kader, 2013). Hence, rapid removal of field heat is crucial to arrest the physiological deterioration, however, apart from this initial cooling, a continuous cool chain would still require along the entire value chain to minimize deterioration and subsequent discard. Management of relative humidity on the other hand (which is a measure of the amount of water that can be held by the atmosphere in the form of water vapor at a temperature and pressure) is particularly important to reduce moisture loss (evaporation losses). The optimum temperature for many of the fruits and vegetables lies close to 0°C (Kader, 2013); the fruits and vegetables which are susceptible to chilling injuries should be stored at relatively higher temperature, for example, ranging from 5°C to 15°C. Similarly, various fresh perishable commodities have their optimum relative humidity, however, in general, all fresh fruits and vegetables require high relative humidity (ranging from 80% up to 100% in some cases) to control water loss and achieving ripening in certain fruits. The temperature management during long-term storage is the key to slow down the physiological and pathological decay of the agricultural produce. From an "on-farm postharvest activities" point of view, precooling to remove the field heat in horticultural produce is an important aspect. However, to ensure the long-term storage and maintenance of desired quality (by retarding the ripening and senescence) it is essential to keep the cool chain conditions all along the food supply chain. Evaporative cooling (zero energy cooling chamber) and night ventilation are some of the effective cooling techniques for smallholder farmers in developing countries who may not have facilities to mechanically precool the produce.

For grain crops such as wheat, maize, rice etc., and dehydrated fruits and vegetables, the water activity is an important parameter. The simplest way of expressing water activity is as follows:

$$Aw = \frac{p}{P^0}$$

$Aw$ = Water activity

$p$ = Partial vapor pressure of the water in the material being measured

$P^0$ = Vapor pressure of the pure water at the same temperature

Water activity is an expression of the amount of water in processed food products or raw materials that is available to support the growth of microorganism. Water activity of food products is directly proportional to the moisture content of

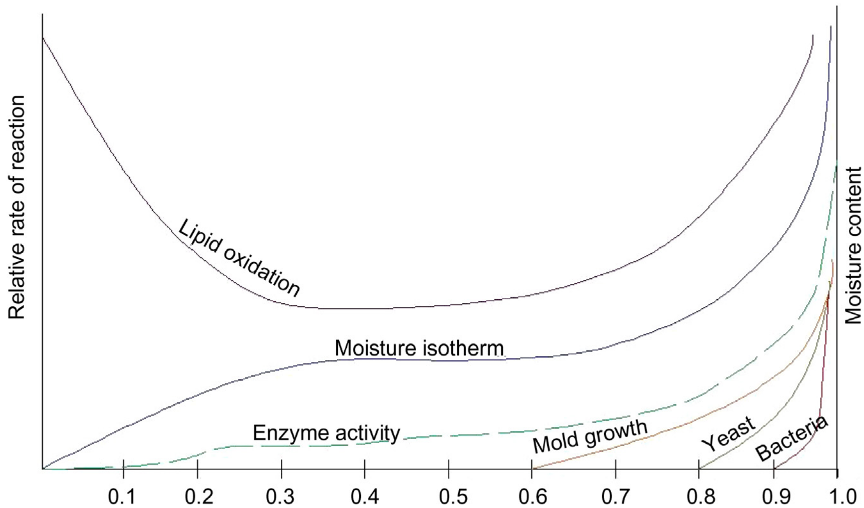


**Figure 3.4** A simplified water activity stability diagram for microbial growth and rate of other reactive degradations.
Source: Adapted from Aqualab, 2018. Water activity. Retrieved July 31, 2018, from: http://aqualab.decagon.com.br/educacao/measurement-of-water-activity-for-product-quality/.

the crop, when moisture content increases water activity rises, which encourages fungal and insect problems, and respiration. A simplified water activity stability diagram is presented in Fig. 3.4.

### 3.4.1 On-farm handling and storage

Improving the storage facility for perishables at farm level is lacking in the developing countries. A significant amount of product is lost due to improper storage at farm and delays in transportation of the product to the market. The contributing factors to deterioration such as temperature, ethylene production, microbial load, pest infestation, moisture content, etc. need to be controlled at the farm gate to ensure better postharvest life.

In relation to perishables (horticultural crops), the durables (cereals and grains) are less susceptible to losses during harvesting and handling. However, the African Postharvest Loss Information System (https://www.aphlis.net/en#/) reports on-farm losses (including harvesting, threshing, winnowing, field drying, on-farm storage) can be in the range of 5%−10% for cereal crops such as wheat, maize, barley, rice, and sorghum (Table 3.5). Storage pests and moisture may make their initial attack at the farm, and the infestation and damage may be aggravated along the value chain as the product travel from farm to consumer.

Condensation in the storage of grains may be caused by temperature fluctuations, and infestation with pests (due to respiratory activity the temperature increases and the environment capacity to hold water increases; as the ambient environment cools

**Table 3.5** Safe moisture content of the stored produce for long-term storage (up to a year)

| Produce | Conventional storage (in sack or silos) % | Hermetic storage % |
|---|---|---|
| Maize | 13 | <10 |
| Wheat | 13 | <10 |
| Millet | 16 | 12 |
| Sorghum | 12.5 | <10 |
| Paddy | 14 | <10 |
| Rice | 13 | <10 |
| Cowpeas, beans | 15 | <10 |
| Groundnuts | 7 | <5 |
| Cocoa | 7 | <5 |
| Copra | 7 | <5 |
| Palm kernels | 5 | <5 |
| Coffee | 13 | <10 |

down the condensation occurs). Hermetic storage may require even lower moisture contents.

Many farmers in the developing regions store their grains in unthreshed form, where the storage period can last from 6 to 12 months. The grains are stored in a variety of traditional storage structures, which are based on socioeconomic, climatic conditions, and availability of local raw materials. The two typical forms of storage systems in developing tropical countries are defined by Gwinner et al. (1990):

1. Open and semiopen storage systems

   An open storage system is suitable for unfavorable hot and humid climates as the freshly harvested grain products may still have higher moisture content, whereas semiopen stores are common in semiarid regions. Raised wooden platforms with a straw roof (protection from rain) on which cobs or panicles are stacked in layers are widespread in the humid tropics. These are simple constructions and have poor store hygiene as insects, birds, and rodents have direct access to the crop; however natural ventilation enables the crop to dry and hinders the development of mold.
2. Closed storage systems

   Closed storage systems are widespread in arid regions and primarily constructed from locally available material such as mud mixed with straw, where crops are stored after threshing. This provides good protection against pests, and has a cool and dry microclimate (especially in mud construction).

## 3.5 Farmer organization, value addition, training, and access to market

The global agricultural economy is rapidly changing due to increased urbanization and globalization. The product supply chains are becoming complex, and there are various opportunities as well as risks that primary producers face due to these trends. The price of common commodities remains static or has even declined in certain cases, so it is desirable that farmers invest in high value crops and take part in value addition by agricultural processing of their produce. There have been several debates whether a public or private sector approach would support the smallholders in achieving these endeavors. Capacity building of the smallholders in the least developed countries is the key to improve the postharvest systems and in turn, reduce food losses and improve livelihoods. Strengthening the smallholder extension services to disseminate knowledge on preharvest and postharvest factors to improve crop shelf life and quality is paramount to achieving sustainable agricultural systems.

Improving the linkages vertically and horizontally along the entire value chain is important to minimize inefficiencies and reduce the risk of market failures (oversupply, price crashing, or gluts). At the same time, encouraging public/private partnerships is necessary to improve the product quality, add value, and enhance the shelf life of perishable crops. It is a common phenomenon (in particular in industrialized countries, but not limited to them) that overproduction leads to higher food losses, as having produced more than needed the excess harvest is sold at lower prices as animal feed or other nonfood purposes or processing (biofuel). Such a situation leads to the economic losses to farmers, which is another way of translating physical or weight losses of food. The prevention of such circumstances can be achieved by enhancing the communication and cooperation among farmers' groups.

Market access is one of the significant problems smallholders in developing regions face, due to disaggregate nature, small production volumes, lack of connectivity to urban markets, and other logistic issues. Farmer groups and cooperatives/associations can help link the smallholders to the market, sometimes with contractual farming for big traders and processors. Hellin et al. (2007) presented a case study from Central America on maize and high-value vegetables and concluded that farmers' organizations were much more effective in the vegetable sector, which is known for its high transaction cost to access markets. Linking producers directly to the market was a key element of this success; it was demonstrated in this case study that when high value vegetable farmers' organizations were directly linked to supermarkets in urban centers, the impact on financial sustainability of these organizations was immense. However, the weakness or the risk that was highlighted was the lack of business skills and nonreplicable structure of these linkages.

In another example from Malawi, Kachule et al. (2005) reported from a semi-structured survey of 12 farmers' organizations the importance of involvement in agricultural processing, food chain management, and development of human capital. Other factors that were a barrier in realizing the full potential of these organizations were lack of financial resources, lack of assets, and limited networking and coordination among them. Critical areas that needed attention were capacity building, networking and linkages, and design of governance systems. Ferris et al. (2014) stated that modernizing the extension services in developing countries can have an impact on millions of smallholders by improving productivity at harvest and postharvest stages. However, the challenges that cannot be addressed by extension alone are the micro- and macroeconomic issues, such as local government structures, high internal transport costs, poor access to inputs, and uncoordinated domestic and international trade policies. Engagement of the private sector along with a stable government and effective policy reforms are some of the solutions that can improve the opportunities to millions of smallholders.

## 3.6 Climate changes and potential impacts on crop postharvest

It is very clear that in the near future and over the long term, our climate is going to change eventually. Some of the Intergovernmental Panel on Climate Change global warming scenarios and increased amounts of various greenhouse gases are illustrated in Figs. 3.5 and 3.6 respectively. Changing climate in the form of increased temperature, increased levels of carbon dioxide and other gases in the atmosphere, rainfall, humidity, and extreme events, not only has an impact on the primary production stages of the agriculture, but also during postharvest. In addition, postharvest losses in themselves are a big contributor to climate change, which is why it is important to reduce losses, otherwise we can be stuck in a vicious cycle of climate change and associated food losses. Estimates from the World Resources Institute suggest that food loss and waste accounts for 4.4 gigatonnes of greenhouse gases. From the food systems perspective, this calls for an improved cooperation between all the value chain stakeholders to develop more diversified cultivars that are more nutritious, reduce soil degradation, have lower or no dependence on unsuitable external inputs (fertilizers, pesticides), have resistance to current and emerging pests, and have increased adaption to the changing climate (Chegere, 2017; Vermeulen et al., 1958). Dwivedi et al. (2017) in a recent review emphasized that climate change is going to pose a serious threat to crop production and protection globally, particularly in the areas of the world that need to significantly

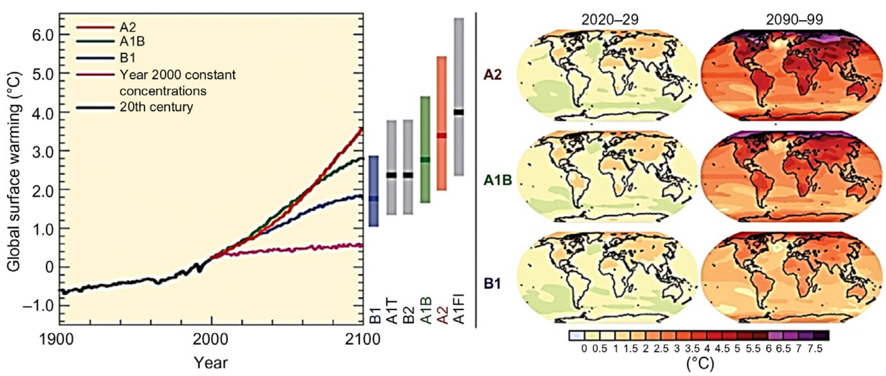


**Figure 3.5** Global warming scenarios.
Source: IPCC, 2007a, AR4-synthesis report, Chapter 3, https://www.ipcc.ch/. Courtesy IPCC.

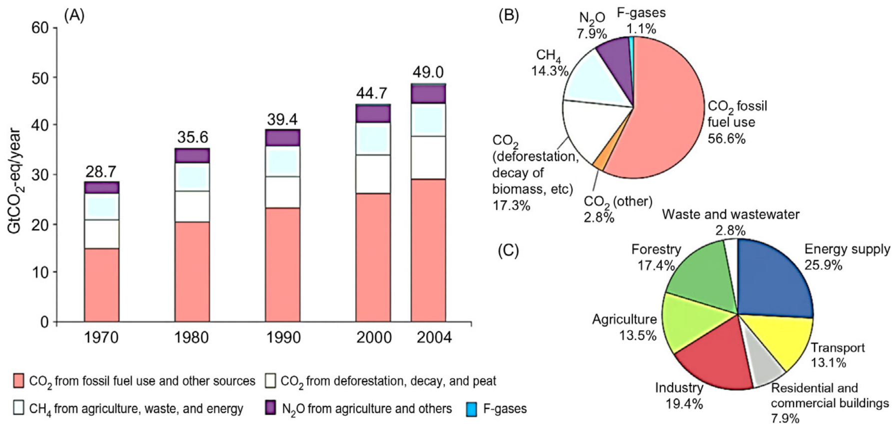


**Figure 3.6** Greenhouse gases and their emissions.(A) Global annual emissions of anthropogenic GHGs, (B) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents (CO2 -eq), (C) The share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO2 -eq.
Source: IPCC, 2007b, AR4-synthesis report, Chapter 2, https://www.ipcc.ch/. Courtesy IPCC.

increase their production due to rising population and urbanization. Some of these areas that are going to have severe effects of climate change are Africa, Mesoamerica, the Andes, and South-Central Asia. A large proportion of populations in these areas have to adapt and adopt mitigation strategies, which are limited in these regions. They will need new crop cultivars that can sustain changing climate during production and postproduction stages, and in such a situation, reduction of food losses will play a significant part. An example of one of the most popular staple crops is maize in Africa; it has been identified that hybrid high yielding varieties tend to be susceptible to insect and pest damage as well as more tolerant to erratic weather conditions than the indigenous crops such as sorghum and millet (Kossou et al., 1993).

Climate change is a key factor that will affect the postharvest systems including changes in temperature, rainfall, humidity, and events of extreme weather (or worst case, natural disasters). Stathers et al. (2013) provided an extensive review paper on the effects of climate change trends on grain postharvest systems of eastern and southern Africa. The postharvest elements that according to this review paper can be significantly affected by climate change are viability of seeds, survival and reproduction of storage insects and pests, performance of storage protectants, and finally the shelf-life of the perishable and durable crops. For example, in a particular example for cereals and grains storage, if moisture, temperature, and gas composition of the storage environment changes this can have considerable effect on increased infestation of fungi, insects, mites, and rodents, which will worsen the postharvest loss situation in already vulnerable regions. One important thing in this respect is that climate change will have different effects in different areas, so the adaptation strategies need to be very regional and local in their nature. Higher temperatures for the storage of grains and other dehydrated food products can mean more rapid growth and infestation of storage insect pests and growth of fungal organisms particularly those that are associated with the production of myco- and aflatoxins. For perishable products, high temperature means shorter shelf life and more energy demands for cooling, which may not be sustainable in many developing countries. Also, insects/pests and crop disease pathogens (in most cases insects and pests are the vectors of these diseases) migrate and expand their territories with global warming, and more land mass would be become suitable in terms of temperature for these insect and pests. Moreover, the increase in temperature and subsequent occurrences of the extreme weather conditions (droughts, flooding, storms, etc.) can induce water stress (excess or deficit) for the crops in preharvest affecting the crop quality postharvest. El-Ramady et al. (2015) stated that in tree crops, which in most cases are not irrigated but depend on the rainfall, the water deficit for tree crops not only would reduce the productivity but also accelerate the ripening process, which influences the postharvest shelf life. Some of the adaptation strategies to increase the resilience of postharvest systems of cereals and grain in eastern and southern Africa to climate change, which were identified by Stathers et al. (2013), are as follows:

1. Improvement and modifications in grain drying and storage management, which will reduce the mycotoxin contamination and storage pest infestation.
2. Appropriate value addition/food processing opportunities based on the local or global (for export for example) demands and food systems.
3. While selecting the crop cultivars for primary production look at the properties for both the pre- and postharvest stages and activities.
4. Improving the market information systems and networks, which will improve the market linkages and capture new market opportunities.
5. Training and learning of extension agents into climate change and its effects on postharvest systems.
6. Investing in more accurate and responsive weather forecast and early warning systems, which will inform various stakeholders of an oncoming weather event that can negatively affect their crop in pre- and postharvest stage.

Coming from the example to cereals and grain crops to fruits and vegetables, studies have shown that an increase in temperature and exposure to increased levels of gases such as $CO_2$ and $O_3$ can directly or indirectly have an effect on the postharvest quality of fresh fruits and vegetables. In an elaborative review Moretti et al. (2010) talked about how increased temperature can lead to changes in photosynthesis and changes in sugars, organic acids, flavonoids, firmness, and antioxidant levels. Whereas higher levels of $CO_2$ in the atmosphere, for example, in potatoes, can cause tuber malformation during production and in postharvest stages leading to problems such as scab disorder and changes in composition of reducing sugars. Moreover, there are several examples where extreme unpredicted hot and wet spells at harvest of vegetables and sugarcane in Vietnam, Indonesia, and Australia resulted in loss of multimillions of dollars (Vermeulen et al., 1958).

Hence it can be said that climate change can seriously affect various stages of the food chain, from the more obvious link to primary production, to various direct and indirect linkages to postharvest problems leading to food losses. The impact of this is expected to be widespread and complex in nature. More emphasis on research and studies is required to gather more evidence regarding the impact of climate on the postharvest food chain, as the present data is limited and scattered.

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