Chapter 1
Overview of Food Loss and Waste in Fruits and Vegetables: From Issue to Resources

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Abstract Vegetables and fruits contain many phytochemicals, vitamins and minerals, and dietary fibers that are good for human health. However, on a global scale, a substantial amount (25–50%) of fruits and vegetables is lost from farm to fork, together called post-harvest losses. These losses represent both food security and environmental issue and therefore counteract any effort to build sustainable food systems since they deprive populations of a considerable amount of healthy food and represent a huge waste of resources. A significant obstacle in achieving mitigation of post-harvest losses is the lack of precise knowledge of the actual magnitudes of losses, which makes it impossible to measure progress against any loss reduction targets. After a brief historical sight on how science addressed the issue, this chapter will present the concepts and definitions of fruits and vegetables food loss and waste and finally review the state of knowledge about the magnitude, distribution in the food supply chain, and main causes of fruits and vegetables food loss and waste for this category of products.

Keywords Fruits · Vegetables · Food loss and waste · Food Loss Index · Post-harvest · Phytochemicals · Vitamins

1 Introduction

Vegetables and fruits contain many phytochemicals, vitamins, and minerals, dietary fibers that are good for human health. Vitamins A (carotene), C, and E, magnesium, zinc, phosphorus, and folic acid are some of the essential constituents. For example, homocysteine, a chemical that may be a risk factor for coronary heart disease, is reduced by folic acid. Fruits and vegetables are also low in fat, salt, and sugar.

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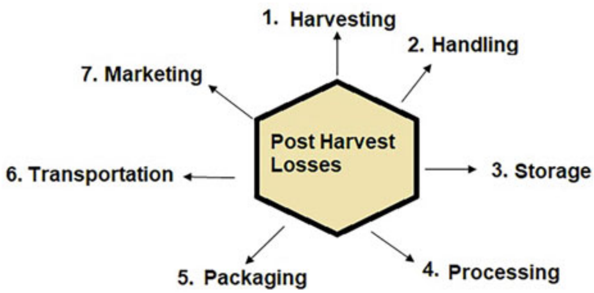

Fig. 1.1 Different stages of post-harvest losses of horticultural commodities

Therefore, a high intake of fruits and vegetables, as part of a well-balanced regular diet and a healthy, active lifestyle, can reduce obesity, lower blood cholesterol, and lower blood pressure. According to the UN's Food and Agricultural Organization (FAO) data, the global fruit production was about 870 million metric tons (MMT) in 2018. Banana production (116.78 MMT) was the highest, followed by watermelon (100.41MMT), apple (87.23 MMT), and orange (78.7 MMT) (https://www.statista.com/statistics/264001/worldwide-production-of-fruit-by-variety/). Vegetables are harvested in vast quantities all over the world—more than one billion metric tons each year. For example, over 834 MMT of fresh vegetables are produced in Asia (https://www.statista.com/statistics/264662/top-producers-of-fresh-vegetables-worldwide/). Tomatoes are the most popular vegetable globally in terms of production volume. However, a substantial amount (25–50%) of fruits and vegetables is lost along the supply chain, together called post-harvest losses (PHL). In horticultural commodities, the PHL can be divided into seven stages: harvesting, handling, storage, processing, packaging, transportation, and marketing (Fig. 1.1). Post-harvest losses are a waste of resources such as land, water, energy, and inputs utilized in production.

The inaugural World Food Conference in 1974 sparked interest in PHL to achieve a 50% reduction by 1985 (Parfitt et al. 2010). There is, however, no account of progress toward the 1985 PHL reduction target. A key barrier to PHL mitigation is the absence of a precise understanding of the real magnitudes of losses, which makes it impossible to monitor success against any loss reduction targets. The focus was initially on reducing grain losses, but by the early 1990s, it had expanded to include roots and tubers and fresh fruits and vegetables.

2 Food Wastes: Concept and Definitions

The Food and Agriculture Organization (FAO) published a report in 2011 titled "Global Food Losses and Waste: Extent, Causes, and Prevention." This widely mediatized study brought a renewed interest in the theme of food losses and waste, considered a sustainable means to improve food security, reduce the pressure on natural resources, and combat climate change. In that way, despite methodological issues, it constituted a trigger for public and private initiatives. The year 2014 was even chosen as the European Year against food loss and waste, and the EU set a target of halving wasted quantities by 2025 (Redlingshöfer and Soyeux 2011).

2.1 A Historical Sight on the Issue of Food Loss and Waste

The World Food Conference in 1974 launched the "Prevention of Food Losses" program, which drew international attention to post-harvest losses (Grolleaud 2002). From that point to the 1980s, research focused mainly on grain storage in rural areas. This trend of reducing post-harvest losses to a single category of plants (cereals) and insect damage was explained because it was mainly the work of entomologists (Guillou and Matheron 2011), and the current FAO's objective to promote policies aimed at improving food availability**.** Not until the 1990s, that field was extended to roots, tubers, and fruits and vegetables (Parfitt et al. 2010). Definition grew more complex, introducing a distinction between quantitative and qualitative loss (Grolleaud 2002), and measurement and estimation methods were improved by Compton et al. (1998), Pantenius (1988), Compton and Sherigton (1999), and La Gra et al. (2016). But from this period, food losses seem to be forgotten.

The 2008 price hike and the awareness of the major changes that await food systems (demographic challenge, climate change, extreme events, resource depletion, etc.) generated renewed interest in food security issues (Esnouf and Huyghe 2015). The disappointing levels of adoption of new technologies led to prioritizing the identification of factors, causes, and conditions of losses throughout the post-harvest chains (Parfitt et al. 2010). The publication of the FAO (2011) report triggered many public and private initiatives as food loss and waste (FLW) reduction was presented as a sustainable means to improve food security, reduce the pressure on natural resources, and combat climate change (Lundqvist et al. 2008; FAO 2011). International attention is now firmly reflected in the 2030 Agenda for Sustainable Development Goal (SDG) and Target 12.3, calling for the halving 2030 of per capita global food losses. The year 2014 was even chosen as the European Year against food loss and waste (Redlingshöfer and Soyeux 2011).

2.2 Definition of Food Loss and Waste Depends on the Issue Targeted

Although the concept of food loss or waste may appear to be straightforward, there is no universally accepted definition of food loss and waste in practice. Despite efforts for standardization, several definitions remain and are used by authors. For this reason, comparison, aggregation, and analysis of data from different sources present methodological issues. For example, Chaboud and Daviron (2017) illustrated that the scope, timing, terminology, and criteria defining FLW are deeply related to the perspectives or issues that stakeholders focus on. They identified two main ways to address FLW: food security issues or food system efficiency and resource use issues.

2.2.1 Food Loss and Waste (FLW) Definition from a Food Security Perspective

The 2011 FAO report defined FLW as *"the reduction, at all stages of the food chain, that is to say from the time of harvest to that of consumption of the mass of edible foods originally intended for human consumption, whatever the cause*" (FAO 2011), introducing the concept of waste, considering FLW from the moment products are ready for harvest (i.e., not just post-harvest) and food not consumed and redirected to alternative uses included as FLW (Chaboud and Daviron 2017). However, in 2019, with the launch of two new indicators that are the **Food Loss Index and the Food Waste Index**, FAO used a slightly different definition:

- **Food loss** is "*the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers, and consumers. Thus, food loss refers to a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption.*"
- **Food waste** is "*the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services, and consumers. Food waste refers to food appropriate for human consumption being discarded, whether or not it is kept beyond its expiry date or left to spoil.*"
- **Quantitative FLW** (also called physical FLW) is "*the decrease in the mass of food destined for human consumption as it is removed from the food supply chain.*"
- **Qualitative FLW** refers to "*the decrease in food attributes that reduces its value in terms of intended use. It can result in reduced nutritional value (*e.g.*, smaller amounts of vitamin C in bruised fruits) and/or the economic value of food because of non-compliance with quality standards. In addition, a reduction in quality may result in unsafe food, presenting risks to consumers' health.*"
- **Products nonintended to human consumption and inedible parts** of food are not considered food and therefore are not included in FLW.
- **The fate of discarded food**: Food diverted to productive nonfood use (as feed or biofuel use) retains part of its value and is not considered loss or waste. Food that ends up in this waste management process (as anaerobic digestion) is included in FLW (FAO 2019).

2.2.2 Food Waste Definition from a Resource Management Perspective

A second definition appears within the framework adopted by the European Commission and the Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) program and puts the issue of post-harvest loss reduction on the perspective of resource management and environment (FUSIONS 2014). FUSIONS framework uses the unique terminology "waste," whatever the cause or stage of the chain. There is no distinction between edible and nonedible parts of an agricultural product. Foods redirected toward animal feed and industry (biomaterials, biorefinery) are described as upgrades or conversions and are not counted as waste. This waste-oriented approach aims to reduce waste of all kinds and limit the negative impacts and costs associated with the treatment of food and nonfood. It often considers the local environmental impact and calls for questioning the fate of waste that can be used as feed, recycled, or produce energy or compost, incinerated or disposed of in a landfill (HPLE. 2014; Chaboud and Daviron 2017).

In the EC framework, "*food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed of (including composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea*)."

2.3 *What Are the Expected Benefits of Saving Foods?*

Feeding over 9.1 billion people with safe food by 2050 is the key challenge for agricultural research, development, and policy (Parfitt et al. 2010). Consequently, food production is expected to increase by 70% to meet the worldwide food supply needs by 2050. It is also forecasted that a growing population and rising incomes will increase demand for agricultural products by 35–50% between 2012 and 2050, exerting even more pressure on natural resources (FAO 2019). Increasing the efficiency of the food system, improving food security and nutrition, and contributing to environmental sustainability are all viewed as significant reasons to minimize FLW (FAO 2019).

2.3.1 Contribute Toward Environmental Sustainability

Three major types of environmental footprints of FLW are generally quantifiable:

- GHG (greenhouse gases) emissions (**carbon footprint**).
- Pressure on land (**land footprint**).
- Pressure on water resources (**water footprint**).

FAO calculated the impact of food waste on natural resources, including its carbon footprint, estimated at 3.6 GtCO2 (total annual anthropogenic GHG emissions) eq, excluding the 0.8 GtCO2 eq of deforestation managed organic soils. This represents about 8% of total anthropogenic GHG emissions. The two other dimensions are addressed by Kummu et al. (2012) that estimated 23% of total global cropland area, 23% of total global fertilizer use, and 24% of total freshwater resources used in food crop production (27 m^3/cap/yr) are dedicated to the production of food is lost or wasted.

Food production is resource-intensive and has substantial environmental consequences from an environmental standpoint. FLW, therefore, represents a huge waste of resources, some of them being nonrenewable. It appears to be a waste of natural resources as well as a squandered opportunity to feed the world's expanding population.

2.3.2 Improve Food Security and Nutrition

Considerable attention has been directed toward increasing food production, which, to provide enough qualitative food to humankind in 2050, should increase by 50–70%. However, on a limited planet, an essential and complementary factor often forgotten is reducing food loss and food wastes (Hodges et al. 2011). Plus, consumers expect food quality and safety across the food supply chain (FSC). FLW occurs at all stages of FSC, primary factors involved in part of their expected revenue and reducing access and availability of food products for consumers. FAO (2011) established that between 208 and 300 kg of food per capita in European and North American countries and 120–170 kg of food per capita in sub-Saharan Africa and South and Southeast Asia are lost or wasted throughout the food chain each year. According to Kummu et al. (2010), around one-quarter of food (614 kcal/cap/day) is lost in the FSC, while almost half of the losses might be avoided with a more efficient supply chain. If food crop losses could be cut in half, one billion more people could be nourished (Kummu et al. 2012).

However, food security is not obtained by a sufficient intake of calories. An unbalanced diet can lead to nutritional deficiencies, affecting the health of vulnerable populations. Therefore, a balanced and healthy diet is required to reach food security. Aside from grains, a variety of fruits, vegetables, root, and tuber crops also contribute significantly to the nutrition and income of millions of people in developing countries. However, these crops incur considerable losses (Akande and Diei-Ouadi 2010; Kitinoja et al. 2011; Lore et al. 2005).

Reducing FLW in fruits and vegetables might contribute to food security by diversifying food intakes and balancing the diet providing key nutritional components such as vitamins and minerals. Yet commodities in these categories have been neglected in past post-harvest studies (Affognon et al. 2015).

2.4 Fruits and Vegetables Have Been Neglected by Post-Harvest Loss (PHL) Researchers

Affognon et al. (2015), reviewing the state of current PHLs in sub-Saharan Africa, showed that global data on FLW are often based on old studies (over 30 years old), partial (focused on storage, and cereals), and obsolete if not untraceable. Kitinoja and Kader (2015) also highlighted the information gaps for fruits and vegetables, stating that missing data and insufficient comprehensive measurements along the entire value chain, as well as reporting on all three aspects of loss, that is, physical, quality, and economic losses, exist for regions, countries, and critical crops. This lack of relevant information about the true extent of loss makes it impossible to measure progress. However, a considerable number of the studies were completed after 2000, indicating a growing interest in PHL research and development (Affognon et al. 2015; Delgado et al. 2017, 2019).

PHLs were primarily gathered by surveys/interviews or sampling/direct measurements (Magalhaes et al. 2021). A case study by Blond (1984), cited in Kitinoja and Kader 2015), shows the importance of the methods. Physical losses of potatoes, grapes, and tomatoes were 17.6%, 28.0%, and 43.2%, respectively, in Egyptian farms and wholesale and retail marketplaces. However, when these same value chain stakeholders were interviewed, they reported average total losses of 8.8, 11.9, and 27.6%, demonstrating that their perceptions of losses were significantly lower than reality. These widely dispersed studies' estimations of PHLs for horticulture crops vary slightly and differ by region, country, harvest, and season, with little explanation of what is assessed, when, or how. It results that in literature, estimates of PHL magnitudes in fruits and vegetables vary widely, from 10% to 70% of the production.

3 Overview of Fruits and Vegetables Loss and Waste

Depending on the commodity, global food losses have been estimated to be in the range of 25%–50% of production quantities, caloric content, and/or market value (Lipinski et al. 2013; FAO 2011).

3.1 Global Data on Fruit and Vegetable Food Loss and Waste

According to some studies, global annual losses and wastage amount to roughly 35% of initial production, or 1.3 billion tonnes of food destined for human consumption (FAO 2011). Fruits and vegetables (together with root and tuber crops) are particularly perishable. Hence substantial losses are unsurprising, especially in areas with poor postproduction infrastructure for managing perishable produces

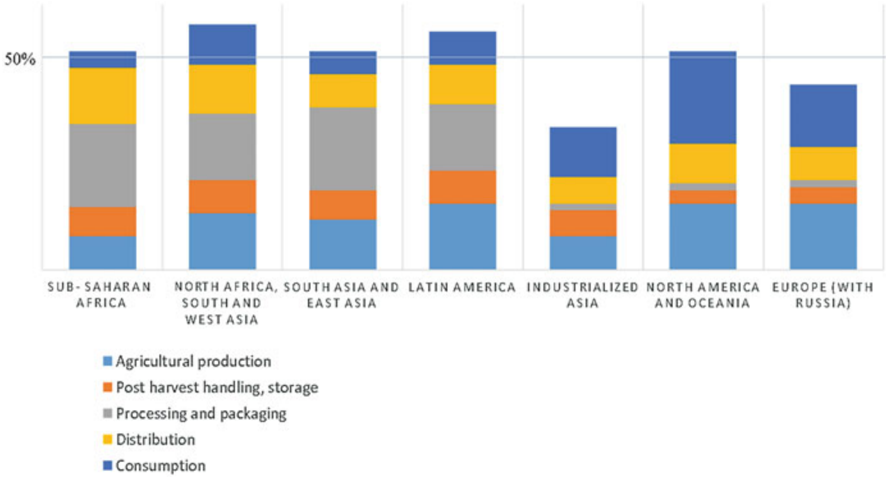

Fig. 1.2 Initial production of fruits and vegetable loss or waste per region and stages of the supply chain (FAO 2011)

(Affognon et al. 2015; FAO 2019). Many international authorities and journal article authors typically quote a general range of 30–50% post-harvest losses. FAO (Food and Agriculture Organization) (2011) currently uses 45% for global losses of both roots/tuber crops and fruits/vegetables (Kitinoja and Kader 2002, 2015). In South Africa, for example, fruit and vegetables, along with roots and tubers, account for 57% of total food waste, whereas fish, seafood, and meat account for only 6% (Diei-Ouadi and Mgawe 2011; Ooelofse and Nahman 2012). Each year, 12 million tonnes of fruits and 21 million tonnes of vegetables are lost in India, according to the Food Corporation of India. Meta-analyses from Xue et al. (2017) and Fabi et al. (2021) concur within the broader amplitude of losses for fruits and vegetables above other groups. Still, the Food Loss Index (FLI) established lower figures, and fruits and vegetables were the second group with a higher level of food losses (22% of production lost) after roots and tubers (25% of production lost) from harvest to distribution (FAO 2019). Since FLI calculation excludes retail and consumer stages, these figures, compared to the study from 2011, show the large contribution of the last steps (retail and consumption) of the supply chain to FLW of fruits and vegetables.

From FAO (2011) (Fig. 1.2, Table 1.1), it is interesting that reported losses and wastes for fruits and vegetables are high in both industrialized and developing countries. However, different patterns in the distribution of loss and waste can be noted. In developing countries, losses in the initial steps of the supply chains tend to be higher than in the last stages. On the other hand, in developed countries, wastes are at the consumer level for all commodities are way more important. The results presented by region also offer evidence of the extent of the higher losses in low-income countries (subtracting consumer wastes). For fruits and vegetables, median losses are estimated to be higher than 10% in Africa and Latin America.

Table 1.1 Distribution of food loss and wastes along fruits and vegetables supply chains

Region	Agricultural production	Post-harvest, handling and storage	Processing and packaging	Distribution	Consumption
Sub-Saharan Africa	10%	9%	25%	17%	5%
North Africa, South and West Asia	17%	10%	20%	15%	12%
South Asia and East Asia	15%	9%	25%	10%	7%
Latin America	20%	10%	20%	12%	10%
Industrialized Asia	10%	8%	2%	8%	15%
North America and Oceania	20%	4%	2%	12%	28%
Europe (with Russia)	20%	5%	2%	10%	19%

Source: Based on FAO (2011) data

In comparison, they range between 4% and 7% in Europe and North America at retail (Fabi et al. 2021). For example, in the United Kingdom, fruit wastage was estimated at 55% of the overall production, 37% at the consumer level. On the other hand, in Rwanda, tomato losses reached 49% of the production, but only 5% were due to consumer behavior. In comparison, 21% of wastage occurred at the production stage and 11.5% at transport and retail (FAO 2019).

3.2 *Fruits and Vegetables Food Loss and Wastes Are Highly Contact and Supply Chain-Related*

Regarding the specific group of foods, the magnitude of FLW varies concerning the region, country, crop, and season. Apart from the development level, the distribution of food losses differs from one region to another. Losses are highest in sub-Saharan Africa. Observations report 15–50% fruits and vegetables on-farm losses (FAO 2019). This very broad range of observations highlights the need to measure losses carefully for specific value chains to identify concretely where significant losses occur (FAO 2019). All regions showed between 0 and 15% of fruits and vegetables are wasted at the retail level, except sub-Saharan Africa, where waste levels can reach up to 35% (excluding outliers), indicating a significant potential for waste reduction in this region (FAO 2019). Northern America and Europe have the lowest percentage of fruits and vegetables wasted at the retail level. However, it is still large (3.75%), and losses exceed 10%, corroborating the findings of high levels of retail waste in high-income countries. Eastern and Southern Asia suffer the highest loss level (around 38%) (Papargyropoulou et al. 2014).

This regional variation could be explained in part by a variety of factors in the literature, all of which are highly context and crop-dependent. Also, the previous assumptions on the highest level of losses in developing countries and their distribution mainly at the initial supply chain stages are verified in many cases. In that case, they can't be generalized (Cappellini and Ceponis 1984).

FLW levels were lower than the 30–50% indicated by Chaboud and Moustier (2021), who analyzed the distribution of tomato losses and waste in Colombia. Fresh produce was reported at the production and post-harvest stages in poor and middle-income nations by the FLW range (FAO 2011; Parfitt et al. 2010). The average percentage FLW across the entire food chain was 13% at the farm level, a little over 1% at the trader level, and 3–4% at the retail level. In the FSC as a whole, the average cumulative percentage FLW was 15–20%. This was owing to a variety of consumer preferences and the relatively high acceptability of substandard produce, a shorter harvest-to-sale time, a variety of marketing strategies used to sell downgraded and damaged products, and the overlap and complementarity of the supermarket and nonsupermarket channels. The authors also mentioned the relatively favorable agroclimatic and infrastructural conditions that characterized the case study. In India, Kitinoja et al. (2019) also found relatively low quantitative losses in the tomato supply chain, with an average of 14% of losses from farm to retail.

The case of cassava also illustrates the difficulty of pulling a general conclusion on the distribution and causes of losses for a specific commodity. Naziri et al. (2014) assessed the extent of physical (quantitative) and economic (qualitative) losses at different stages of cassava value chains in four countries: Ghana, Nigeria, Vietnam, and Thailand. The results showed that the cultural practices and level of infrastructure, processing, industrialization, and consumption patterns could make a significant difference (Table 1.2). Ghana incurred a higher rate of physical loss (12.4%), followed by Vietnam (6.7%). But Vietnam was first and Ghana second regarding the volume of roots affected by economic losses. Finally, in monetary value, losses were ten times higher (500 million USD) in Ghana than in any other region, mostly related to physical losses. The most industrialized country, Thailand, had the highest percentage of loss at the harvesting stage of cassava due to unnoticed roots and breakages related to mechanized harvesting, while manual harvesting and gleaning limit losses in the three other regions. In Ghana, cassava roots are transported fresh over considerable distances because processing is a household activity leading to a high level of post-harvest deterioration and losses at transport and retail. Nevertheless, losses at processing can still be substantial, and it appears that they affect the traditional processing sub-chains (*Gari* in Nigeria and chips in Thailand and Vietnam).

This example illustrates the type of loss assessed and how to present them. Instead of absolute (kg) or relative (% of production), value or volume unit against monetary value may affect the interpretation globally.

Fruits and vegetables also incur substantial monetary value losses—when their quality deteriorates. Volumes ranging from 4.8 to 81% at farm level, 5.4–90% at the wholesale level, and 7–79% at retail level suffer damage, spoilage, or decay, resulting in economic value losses estimated at 16–40% for various fruits and

Table 1.2 Distribution of losses in cassava value chains

Country	Losses by stage (%)				Total losses at national scale		
	Harvest	Trading, transport, and handling	Processing	Retail and consumption	Total physical losses (t)	Total physical loss (% of national production)	Value of economic losses (million USD)
Ghana	2%	6%	17%	**76%**	**1,752,287**	12.4%	520
Nigeria	12%	6%	**82%**	0%	481,258	6.7%	50
Thailand	**70%**	0,4%	0,4%	29%	500,424	2.5%	50
Vietnam	7%	18%	**73%**	2%	304,893	3.1%	35

Source: Naziri et al. (2014)

vegetables (tomato, amaranth, okra, oranges, mango (Kitinoja and Cantwell 2010; Kitinoja and Al Hassan 2012). For example, in Niger, 15% of dried onions and potatoes were discarded (physical losses), but on the rest, 65% ended sold at a lower price due to low product quality (Tröger et al. 2007). The same situation was observed in Kenya, where 30–50% of dessert bananas were sold at a reduced market value (for 11, 2% physical losses) (Save food. 2014).

Food quality degradation can lead to nutrient degradation and bio-contamination, resulting in a loss of food value and the emergence of food-borne health risks. Poor processing, preservation, and storage technologies were partly responsible for the significant losses of micronutrients (Kitinoja and Kader (2002, 2015).

Table 1.3 summarizes results from previous researches on the extent of food losses in fruits and vegetables in different parts of the world. From this, it appears that most of the research data on fruits and vegetables food loss and waste refer to a few species. Potatoes, cabbage, onions, and tomatoes have been the most extensively researched vegetables, followed by a few fruit crops (mango, dessert banana, oranges, among others). Percent losses are sometimes given as averages of several or many crops (Fehr and Romao 2001; Underhill and Kumar 2014) or averages for a single crop across multiple countries (Fehr and Romao 2001; Underhill and Kumar 2014) (Weinberger et al. 2008).

Overall, we can be disappointed that the levels of reported losses for fruits and vegetables worldwide do not appear to have altered much since the 1970s, based on estimates of 30–40% losses published by the National Academy of Sciences in the United States.

4 Causes of FLW in Fruits and Vegetables

The causes of FLW are numerous and vary according to the stages of the food supply chain, the regions studied, and the food product under consideration (Gauraha 1999; Magalhaes et al. 2021).

4.1 Perishability of Fruits and Vegetables Partly Explains Their High Level of Loss and Waste Among Other Food Products

The main cause of post-harvest loss of fruits and vegetables is their high to very high perishability. Fruits and vegetables usually travel through the supply chain as fresh, unprocessed products. They continue to metabolize and consume their nutrients throughout their shelf life, from harvest through packing, distribution, marketing, and sale (Ray and Ravi 2005; Tomlin et al. 2010). Respiration, enzymatic breakdown, and microbial populations actively contribute to the degradations of

Table 1.3 Level of food losses in fruits and vegetables from literature

Region and country	Commodity	Method used	Losses	Reference
Sub-Saharan Africa				
Benin	Tomato	Sampling	28% in volume; 40% in economic value in 5 days	IITA (2008)
Benin	Tomato		23% at handling and storage, 31.3% at marketing (re-sorting)	Kitinoja et al. (2011)
	Leafy vegetables		17.3% losses at handling and storage, 31% at marketing (re-sorting)	
Benin	Lettuce		Lettuce: 36% at production, 22% at wholesale, 9% at retail	Kitinoja et al. (2011)
	Tomato		Tomato: 13% at production, 8% at wholesale, 12% at retail	
Benin	Mango		17–73% losses at harvest	Vayssieres et al. (2008)
Cameroun	Cassava	Survey and sampling	Gari supply chain: 40.4% Cassava stick supply chain: 37.7%	FAO (2018)
Cameroun	Tomato	Survey and sampling	33.8% (with 28.3% only pre-harvest and harvest and 5.5% at transport)	FAO (2018)
Cameroun	Potato	Survey and sampling	45.90% (34% in pre-harvest and harvest stage; 9% storage, 2.8% at retail)	FAO (2018)
Ghana	Tomato	Interviews	20%	Bani et al. (2006)
Ghana	Tomato	Sampling	25% (farm); 21.5% (wholesale); 23% (retail) physical losses	WFLO (2010)
Ghana	Yams	Sampling	25–63% price discount depending on degree of quality losses	Bancroft et al. (1998)
Kenya	Banana (imported from Uganda)	Sampling	18.2–45.8%	George and Mwangangi (1994)
Kenya	Dessert banana and plantains	Survey and sampling	11.2% physical losses; 30–50% reduced market value 4.6% physical losses; 20–30% reduced market value	Save Food (2014)

(continued)

Table 1.3 (continued)

Region and country	Commodity	Method used	Losses	Reference
Niger	Dried onions and tomatoes	Sampling	15% discarded; 65% sold with high levels of quality losses	Tröger et al. (2007)
Nigeria	Tomato	CSAM (survey)	10–40% from the farm to the retail market (15.2% average)	Kitinoja et al. (2019)
Nigeria	Tomato Bell pepper Hot pepper	Survey	20% (farm); 28% (transit) 12% (farm); 15% (transit) 8% (farm); 10% (transit)	Olayemi et al. (2010)
Nigeria	Yam	Survey	12.4% (economic loss = 10.5%)	Okah (1997)
Rwanda	Tomato	Commodity system assessment methodology (survey)	50–60%. From the farm to the retail market (18.3% average)	Kitinoja et al. (2019)
Rwanda	Tomato	Sampling	7.8% (farm); 10.7% (wholesale); 14.7% (retail) physical losses	WFLO (2010)
Tanzania	Sweet potato	Sampling	32.5–35.8%	Rees et al. (2001)
Tanzania	Sweet potato	Sampling	86% damaged (post-harvest handling and transport) 9% loss of market value	Tomlins et al. (2000)
Tanzania	Sweet potato		23.7–66.9%	Tomlins et al. (2007)
Tanzania	Fruits	Survey	0–33% physical loss; 5–80% of traded fruits suffering from quality loss	Ohiokpehai et al. (2009)
Tanzania	Vegetables	Survey	0.4–35% physical loss; 0.5–60% of traded vegetables suffering for quality loss	Ohiokpehai et al. (2009)
South Africa	Grapes	Sampling	Physical loss: 5.9–13.9% at farm, storage: 2.4–7.4% at storage, 3.6% at retail, 4.4% at export. Economic impact: 17 million USD/year	Ooelofse and Nahman. (2012) and Blanckenberg et al. (2021)
Asia				
Cambodia Laos Vietnam	Tomato	Survey	24.6% 16.9% 19.1%	Weinberger et al. (2008)

(continued)

Table 1.3 (continued)

Region and country	Commodity	Method used	Losses	Reference
Cambodia Laos	Yard-long bean	Survey	21.8% 12.2%	Weinberger et al. (2008)
Laos Vietnam	Chili pepper	Survey	10.7% 16.9%	Weinberger et al. (2008)
Fiji	Fruits and vegetables	Sampling	0.07–2.44% 4.07–10% In municipal markets	Weinberger et al. (2008)
Bangladesh	Fruits and vegetables	Survey	23.6–43.5%	Kamrul Hassan et al. (2010)
Bangladesh	Litchi	Survey	8% at harvest 4.6% during handling 7.5% by consumer	Molla et al. (2010)
India	Tomato	Commodity system assessment methodology (survey)	1–18% from the farm to the retail market (14% average)	Kumar et al. (2006); Kitinoja et al. (2019)
India	Potato	Sampling Sampling	29.4% (16.2% economic loss) 10.5%	Ajay and Singh (2004); Pandey et al. (2003); Kumar et al. (2004) Kumar et al. (2006)
India	Onion	Sampling Sampling	12.9% 15.7%	Ajay et al. (2003); Kumar et al. (2006) Chaugule et al. 2004)
India	Tomato	Sampling Interview Sampling	11.0–21.4% 35% 1% economic loss	Pal et al. (2002); Sharma et al. (2005) Gajbhiye et al. (2008) WFLO (2010)
India	Cauliflower and cabbage	Interviews	15–20% 15–20%	Pal et al. (2002); Gajbhiye et al. (2008)
India	Curcurbits	Sampling	52% economic loss	WFLO (2010)
India	Bell pepper	Sampling	6.7–17.1	Sharma et al. (2005)
India	Mango	Sampling	20% economic loss	WFLO (2010)
India	Okra	Sampling	20% economic loss	WFLO (2010)
India	Litchi	Sampling	30% economic loss	WFLO (2010)
India	Banana	Sampling	28.8% (wholesale); 18.3% (cooperative)	WFLO (2010)
Nepal	Cauliflower, cabbage, and tomato		47%: 6% (farm), 41% (retail), 43%: 9% (farm), 34% (retail) 10%: 3% (farm), 7% (retail)	Udas et al. (2005)

(continued)

Table 1.3 (continued)

Region and country	Commodity	Method used	Losses	Reference
Pakistan	Tomato, potato, and onion	Survey	20% 22, 12.9%	Mujib-Ur-Rehman et al. (2007) Zulfiqar et al. (2005)
Pakistan	Mango	Survey	20–30%	Mushtaq et al. (2005)
Sri Lanka	Bananas	Survey	20% from farm gate to retailer	Wasala et al. (2014)
Sri Lanka	Tomato	Survey	54% cumulative (measured at wholesale market)	Rupasinge et al. (1991)
Thailand	Cabbage and leaf lettuce	Sampling	28–32% 50–60%	Boonyakiat (1999)
North Africa/Middle East				
Egypt	Oranges and tomatoes	Sampling	14% 15%	El-Shazly et al. (2009)
Iran	Grapes	Survey	13%	Jowkar et al. (2005)
Jordan	Tomato, eggplant, pepper, and squash	Sampling	18% (tomato), 19.4% (eggplant), 23% (pepper), 21.9% (squash)	El-Assi (2002)
Oman	Fresh produce	Survey	3–19%	Opara (2003)
Saudi Arabia	Tomato, cucumber, figs, grapes, and dates	Survey	17% (tomato), 21.3% (cucumber), 19.8% (figs), 15.9% to 22.8% (grapes), 15% (dates)	Al-Kahtani and Kaleefah (2011)
Latin America				
Brazil	Tomato, bell pepper, and carrot	Interviews	30% 30% 12%	Vilela et al. (2003)
Brazil	Pineapple, banana, orange, papaya, and passion fruit	Sampling	Total 19.3%: 11.6% (wholesale), 7.7% (retail)	Kitinoja and Kader (2015)
Brazil	Fruits and vegetables	Interviews	16.6% (marketing chain); 3.4% (consumer)	Fehr and Romao (2001)
Colombia (Cali)	Tomato	Interviews	Cumulative average of unsold tomato: 15–20%; 13% at farm, 1% for traders, 3–4% at retail	Chaboud and Moustier (2021)

Adapted from Kitinoja and Kadar (2015), Blanckenberg et al. (2021), Chaboud and Moustier (2021)

Table 1.4 Food losses versus perishability of fruits and vegetables

Crops	Level of perishability	Food loss and wastes %	Country	Source
Guava	High	42.9	Ethiopia	Tadesse (1991)
Tomato	High	19.4		
Carrot	Low	1.1		
Tomato	High	30	Brazil	Vilela et al. (2003)
Carrot	Low	12		

Source: Tadesse (1991) and Vilela et al. (2003)

macronutrients, vitamins, and other nutrients, often resulting in reduced quality or quantity of the foods. These processes are highly dependent on the conditions of the food products, such as temperature, humidity, or insulation. Controlling these parameters is the first step to improving shelf life. Some natural or synthetic chemical compounds can also slow or accelerate the natural degradation (CO_2, ethylene, etc.) of fruits and vegetables or contribute to microbial control/inhibition. Finally, mechanical damages during harvest and post-harvest handling, transportation, or storage can lead to faster metabolic degradation or contaminations (Ndunguru et al. 2000; Ray and Ravi 2005).

Physical damage is a leading cause of post-harvest losses, and the extent of losses is often determined by the commodity's relative susceptibility to physical damage (Kitinoja and Kadar 2015), with more delicate and perishable produce suffering higher losses than less perishable produce (Kitinoja and Kadar 2015) (Table 1.4).

The range of reported losses for diverse crops is extensive (0–80%), which is most likely linked to the perishability of the yield. However, various factors contribute to the high level of food losses, including initial illness incidence in the field, time from harvest, the temperature during handling, weather conditions, kind of packaging used, and so on (FAO 2019).

4.2 *Main Drivers Behind Food Losses in Fruits and Vegetables Supply Chains*

Food loss and wastes in vegetables and fruits have several roots, resulting from technical or organizational lacks and failure often combined with unfavorable external conditions.

- **Pre-harvest and harvesting practices**: Rough handling during harvest, harvesting at an early or late stage of maturity, lack of proper harvesting material, lack of shade or dedicated space to store harvested fruits and vegetables, and inadequate sorting and grading practices can lead to loss at production and later stages of the supply chain.
- **Inadequate transportation systems**: These result in mechanical, physiological, and microbial damage, which may lower fresh produce quality or promote their

Fig. 1.3 Inappropriate and overcharged packaging of eggplants in bags (**a**) and tomatoes in cardboards (**a**, **b**) (Picture: Victoria Bancal)

rejection. The other reasons are poor roads, breakdowns, lack of proper vehicles, delay in the time between harvest and distribution, and more prolonged produce exposure to bad weather conditions. Moreover, transported in open, unrefrigerated trucks, and other food and nonfood products, it suffers a mechanical injury (compression, abrasion) and rough handling, making them highly vulnerable to qualitative losses.

– **Inadequate or defective packaging**: In low-income developing countries, fruits and vegetables tend to be either poorly packed (Fig. 1.3a, b): wooden crates, overload cardboard, reused plastic bags; or not packed at all. Improper packaging can damage the product, leading to FLW. Furthermore, some fresh products packaged together may cause FLW (e.g.,, a bulk bag of rotten fruits may go unsold) (Dari et al. 2018). However, where crates are used during transit, both quantitative and qualitative losses (product rejected) are significantly reduced (damaged but still saleable).
– **Poor handling and operational performance**: These factors cause mechanical and microbial decomposition of fresh items; rough handling by different FSC members, along with an advanced state of maturity, frequently causes mechanical damage and shortens the shelf life of products, accelerating physiological and microbial damage (Sibomana et al. 2016). Inadequate harvesting equipment and complex handling during harvesting cause bruising and increase the chances of the product coming into contact with the soil, resulting in microorganism contamination.
– **Lack of processing capacity**: It leads to fruits and vegetables being sold primarily in fresh form with a short shelf life. This is primarily the case in developing countries, where modern equipment are lacking, and processing is mainly done on a traditional small scale.
– **Lack of coordination and information sharing among stakeholders of the FSC**: It is also a contributing factor in FLW. According to Mena et al. (2014), the lower the levels of FLW in FSCs, the closer the ties between retailers and suppliers. Lack of information systems on price or production prediction results

in seasonal overproduction at market saturation in developing countries. At the same time, a wrong estimation of the demand may affect food losses at retail markets in developed countries.

- **Poor storage and temperature management**: Fresh products are prone to suffer physiological flaws such as dehydration, freezing, chilling, sunburn, sunscald, and internal breakdown when stored at the incorrect temperature at any stage of the FSC, whether due to a shortage of cold storage and storage facilities or a gap in the cold chain (Dubey et al. 2013). According to Parfitt et al. (2010), 30% of India's fresh fruit and vegetable production is squandered due to a lack of adequate storage facilities. On the other hand, losses in fruits and vegetables in Tanzanian markets were mainly attributed to inadequate cool chain management. But storage facilities also protect food from rodents and insects attack (Ohiokpehai et al. 2009).
- **Climate change and weather variability**: Crop losses in the field can be caused by climate change and weather fluctuation. Crops may suffer obvious damage due to extreme weather events, leading to their rejection. In their contracts with retailers, farmers frequently produce more than specified to account for unpredictable weather situations, resulting in unnecessary overproduction and waste. Where storage facilities are not available, products are expected to be more exposed to rainfall and high temperatures.
- **Sensorial or microbial deterioration**: The natural deterioration of fresh food's physiological, biochemical, and microbiological qualities is linked to sensory or microbial decline. This deterioration is accelerated by factors such as temperature and humidity, which can develop visible defects and rejection (Buzby et al. 2014). Furthermore, diseases and insect pests can significantly impact the pace of microbiological deterioration of fresh products (Fig. 1.4).
- **Short shelf life or expired products**: Fresh products are rejected due to expiration of best-before or sell-by dates or actions taken in collaboration with the FSC that jeopardize the products' shelf life. Fresh products might also go unsold because consumers prefer products with longer expiration dates, believing that a product nearing its expiration date is no longer fresh (Mena et al. 2014).
- **Nonconformance to standards**: Product exclusion can be facilitated by improper weight, unsuitable sizes, forms, or textures of fresh food, as well as evident mechanical or microbiological faults, even if the products are still fit for human consumption. In addition, the presence or absence of appropriate legal criteria can influence whether or not a vegetable or fruit is eventually accepted for human consumption. However, legal standards differ from country to country and are impacted by the population's economic condition and pressure on fruit and vegetable consumption (Sibomana et al. 2016).
- **Overproduction, excessive stocks, and inadequate demand forecasting**: Overproduction might occur due to inaccurate demand forecasting or as a result of agreements with merchants. Combining the characteristic short shelf lives of fresh products with demand fluctuations makes ordering difficult and often leads to overproduction.

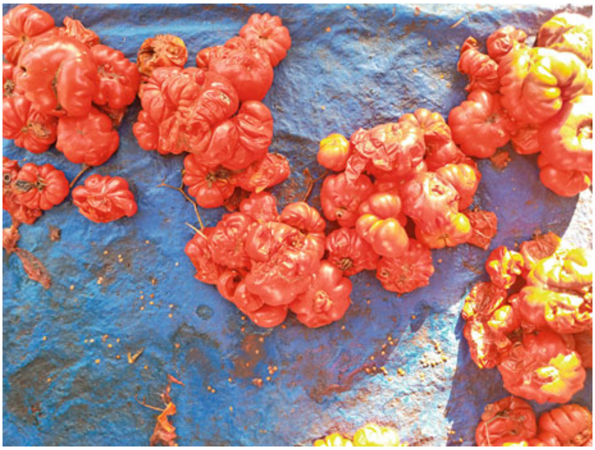

Fig. 1.4 Partly rotten tomatoes sold at a lower price in an Abidjanese market (Picture: Victoria Bancal)

The causes of FLW are not mutually exclusive, and there is a paucity of knowledge about which factors are more influential and how they interact. Causes differ at all stages in food systems and between industrialized as in developing countries and nonindustrialized as in underdeveloped countries. Losses at the production stage are the most important for all industrialized regions, largely due to the sizing of post-harvest fruits and vegetables, the criteria of which are imposed by the distributors. Losses do occur during storage in high-income countries. Nonetheless, they are usually caused by technical breakdown, poor temperature or humidity management, or overstocking. On the other hand, poor infrastructure causes more fresh fruit and vegetable loss in low-income nations than in developed countries (FAO 2019).

5 From Issue to Resources

Fruits and vegetables are the crop group with the highest range of food loss and waste. Their nutritional content makes them great contributors to a healthy diet. Finally, their production, distribution, and disposal as waste require inputs and renewable and nonrenewable resources. As a result, reducing FLW in this category of items should be considered as achieving additional goals, such as increased food system efficiency, enhanced food security and nutrition, and improved environmental sustainability. Policymakers prioritize these different dimensions and will orient the most appropriate interventions to reduce FLW (FAO 2019).

On the other hand, fruits and vegetable wastes (FVW) usually have a composition of sugar, starch, proteins, phenolic phytochemicals, and minerals (Table 1.5), and therefore, they should not be treated as "wastes" but rather as raw materials for other industrial processes. The existence in these FVWs of sugar/starch as a source of carbon, protein as a source of nitrogen, nutrients, and moisture provides conditions

Table 1.5 Biochemical compositions of some vegetables and fruit wastes

Fruit/vegetable waste	Biochemical composition (% w/w)								
	Cellulose	Hemi-cellulose	Lignin	Ash	Total solids	Moisture	Total carbon	Total nitrogen	References
Potato peel waste	2.2	–	–	7.7	–	9.89	1.3	0.48–0.8	Singh et al. (2012); Pathak et al. (2017a)
Cauliflower waste	17.32	9.12	5.94	4.32–5.76	–	81–89	34.48	13.8	Khedkar et al. (2017)
Peapod waste	32.08	21.12	21.58	4.8– 5.20	11.0–39.0	73.5–88.5	–	10.58	Nimbalkar et al. (2018)
Onion peels	–	–	–	4.7– 4.8	91.0	82.0–92.6	–	–	Singh et al. (2012)
Tomato wastes	30–32	5–18	–	3.1–5.3	7.0–22.4	85–90	–	2.72–3.52	Singh et al. (2012)
Carrot peels	13–52	12–19	–	3.8–8.9	7.0–11.0	–	–	0.8–1.28	Singh et al. (2012)
Orange peels	9.21%	10.5%	0.84%	3.5%	–	11.86	–	–	Joshi et al. (2012)
Apple pomace	5–10	4–25	15–25	5.8–6.7	–	15–28	–		Comen et al. (2019)
Pineapple peel	35–50	19.7–35	5–10	4.6–5.8	93.6	75–80	40.8	0.99	Khedkar et al. (2017)
Banana peel	12.17	10.19	16.0	5.01	–	9.65	40.24	1.38	Pathak et al. (2017a, b)
Mango peel	9.2	14.5	4.25	–	–	–	–	–	Gowman et al. (2019)
Papaya peels	–	–	–	3.15–5.25	31–45	54–68	38.10	1.49	Joshi et al. (2012)
Pomegranate peels	–	–	–	–	–	–	–	–	Pathak et al. (2017b)

ideal for the growth of microorganisms, and this opens up great opportunities for their valorization in manufacturing chemicals such as enzymes, organic acids, polysaccharides, sugar alcohols, biocomposites, and biofuels, that is, biochar, bioethanol, biogas, biohydrogen, and biobutanol. FVW generated can be a raw material for other industries (biofuels, biochemicals); hence, researchers should focus on "waste to wealth"—creating a circular economy.

6 Conclusion and Future Perspectives

Fruits and vegetables are a part of a well-balanced regular diet. However, a substantial amount of these commodities is lost from harvesting, handling storage, and marketing during the supply chain. It was not until the 1990s the post-harvest losses of fruits, vegetables, roots and tubers, and plantation crops were given sufficient attention. International attention on the issue is now firmly reflected in the Agenda 2030 for SDG to reduce post-harvest losses of all food crops and valorize wastes into various bioproducts for human and animal consumption as dietary supplements and other valuable products. However, the literature review on the magnitude of losses in fruit and vegetables showed an extensive range of losses from the same crop. For example, the Tanzanian sweet potato value chain suffered a range of 0–33% quantitative losses and 5–80% qualitative losses; in Nigeria, tomato losses were estimated between 10% and 40% from farm to retail (Kitinoja et al. 2019) while under 10% in Nepal (Udas et al. 2005). In front of this complexity, any solution designed to prevent, recycle, or dispose of fruits and vegetables FLW should be context-related and not expected to be generalized to all categories of fruits and vegetables or regions. In addition, information gaps on several crops and regions have to be filled to monitor progress. Finally, the balance between cost and benefits (social, economic, and environmental) of implanting solutions for preventing FLW should be considered while designing these solutions. Therefore, prevention may not always be the most sustainable path to building sustainable food systems. Therefore, research on valorizing the internal properties of surplus or discarded and deteriorated fruits and vegetables should not be neglected.

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