Status Paper

Global Initiatives to Reduce Post-Harvest Food Losses and Waste

Authors:

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Sponsored by

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Foreword

Reducing "Food Losses and Waste (FLW)" is essential in a world where the number of people affected by hunger has been slowly on the rise in recent years, and tons and tons of edible foods are lost and/or wasted every day. It undermines the sustainability of our food systems.

Globally, around 14 percent of food produced is lost between harvest and retail, while an estimated 17 percent of total global food production is wasted (11 percent in households, 5 percent in the food service, and 2 percent in retail). Food losses also mean that there is wastage of precious resources like water, land, energy, labour, capital besides other inputs. In addition, the disposal of food loss and waste in landfills, leads to greenhouse gas emissions, contributing to climate change.

Food loss and waste can also negatively impact food security and food availability, and contribute to increasing the cost of food. Food that is lost and wasted accounts for 38 percent of total energy usage in the global food system. According to estimates by the ICAR- Central Institute of Post-Harvest Engineering and Technology (CIPHET), India lost INR 926.51 billion worth of food in 2014. The highest loss was in fruits and vegetables, followed by oilseeds, pulses, and cereals. However, the efforts to reduce Post-Harvest Losses in subsequent years led to some reduction in the losses as shown by the NABCONS (2022) study which revealed that the monetary loss was reduced by INR 204.41 billion annually in India due to reduction of Post-Harvest Losses (PHL). ILSI India Network for Checking Post-Harvest Losses (*I-NET*) recommended that we should look at global initiatives to check post-harvest losses. Furthermore, the *International Day of Awareness of Food Loss and Waste (29 September)* is an opportunity to call to action both the public (national or local authorities) and the private sector (businesses and individuals), to prioritize actions and move ahead with innovation to reduce food loss and waste towards restoring and building back better and resilient food systems.

Closely connected to offering food and nutrition security is the issue of checking post-harvest losses. Food losses need to be checked in the entire food chain from Farm to Fork including fields, transport, storage, retailing, processing, and consumption stage. Our food systems cannot be resilient if they are not sustainable, hence the need to focus on the adoption of integrated approaches designed to reduce food loss and waste. Actions are required therefore, globally and locally to maximise the use of the food we produce. The introduction of technologies, innovative solutions (including e-commerce platforms for marketing, and mobile food processing systems), new ways of working, and good practices to manage food quality and reduce food loss and waste are keys to implementing this transformative change.

Keeping all the aforesaid issues in view the present study has been commissioned. The Status Paper on "Global Initiatives to Reduce Post-Harvest Food Losses and Waste" is first of its kind study in the world and shares the perspectives on the issues and actions required to stem the problem of food loss and waste. ILSI India thanks and acknowledges the contributions of Dr. R. K. Vishwakarma and Dr. Nachiket Kotwaliwale in this regard. Moreover, the publication attaches its close link with the United Nations Sustainable Development Goal (UNSDG) No. 2 out of a total of 17 Goals.

It is hoped that the Status Paper will be useful to the stakeholders and help in formulating strategies to check post-harvest losses and waste.

Dr. B. K. Nandi
Chairman, ILSI India

Preface

The ever-increasing human population throughout the world, particularly in the developing and undeveloped countries, is posing serious challenge to provide safe and quality food to the masses. Increasing agricultural production along with appropriate distribution through technological interventions is one way to meet the additional food demand. Major efforts are being made to increase production as sustainably as possible through optimized soil and water management, plant and animal breeding, better feed conversion, improved fertilization, more efficient organic farming, control of trans-boundary plant and animal diseases, etc., in order to produce more food with limited resources and on limited arable land. But none of these above efforts and technologies, and hardly all of them together, can even come close to reducing the gap we face from food losses and waste, worldwide.

Another major step could be by saving the produced commodities from losses in fields, transport, storage, retailing, processing etc. without straining the fields, water and environment. Further, non-consumption or throwing the food after processing and value addition creates serious social, economic and environmental concerns. This kind of wastage is simply not acceptable as millions go to bed hungry every night globally. The epidemic/ pandemic, climate change and wars also have serious bearing on food loss and waste. Therefore, "A grain saved is equivalent to a grain produced" in the food supply chain is the apt idea for the present era.

Post-Harvest Losses and Food Waste vary among geographies in the world. It largely depends on the crops and commodities, duration of storage, climate, technological interventions, human behaviour, traditions etc. The importance of 'Food Loss and Waste' has been recognized at the apex level too and this was one of the issues discussed during the G20-Meeting of Agricultural Chief Scientists (MACS) held in Varanasi, India during April 2023. It was noted that despite the abundant agricultural production, a substantial amount of food is lost or wasted throughout the food supply chain, from production to consumption, and impacts food security and availability, environment, economy and the society; this hold higher significance for the regions which are major food producer as well as consumer of food.

We only have a few years left to achieve the sustainable development goal 12.3 to reduce the food losses to half by 2030. The efforts to reduce the food losses and wastage are required by addressing the issues like Assessment and Impact of Post-Harvest Losses and Food Waste; Prevention of Post-Harvest Losses in the Supply Chain; Prevention of Food Waste in Households and Community Activities and Role of Food Bank Networks and Circular Economy. Diagnosis of the problem and taking stock of the possible solutions is imperative for forming and practicing any policy; therefore, this document has been prepared with the aim to learn and share the challenges and best practices across the globe and to create awareness among consumers.

The term 'Food Loss and Waste' has many dimensions and we have tried to cover all those so as to provide a bird's-eye-view of the situation. This document also provides information on: definitions of the terms being used, various processes and protocols being employed to estimate the losses, available data for various geographic regions, plausible causes of loss and waste, various impacts of loss and waste, basic and advanced scientific practices and indigenous technical knowhow to curb the losses and wastage, policies of various countries to reduce food waste, etc. We hope that this document serves as useful reference for scientific as well as social community and helps for developing new practices and policies to reduce the menace due to Food Loss and Waste.

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Acknowledgements

The authors acknowledge the financial help, guidance and some data support made available by ILSI India. The authors thankfully acknowledge the help provided by Dr. Raouf Asalam, SRF in AICRP on PHET, Ludhiana in preparation of this document.

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List of Abbreviations

AD	Anaerobic Digestion
APEDA	Agricultural and Processed Food Products Export Development Authority
AVG	Amenoethoxyvinyl Gycin
AVRDC	Asian Vegetable Research and Development Centre
CA	Controlled Atmosphere
$Cacl_2$	Calcium Chloride
CAP	Cover and Plinth
CAS	Controlled Atmosphere Storage
COMCEC	Committee for Economic and Commercial Cooperation
DARE	Department of Agricultural Research and Education
EU	European Union
ECC	Evaporative Cooling Chamber
EMAP	Equilibrium Modified Atmosphere Packaging
FASDEP	Food and Agriculture Sector Development Policy
F&V	Fruits and Vegetables
FAO	Food and Agriculture Organization
FBS	Food Balance Sheet
FL	Food Loss
FLW	Food Loss and Waste
FW	Food Wastage
GADS	Gender and Agricultural Development Strategy
GAP	Good Agricultural Practices
GHG	Green House Gases
GMP	Good Manufacturing Practices
GPRS	Ghana Poverty Reduction Strategy
GRDC	Grains Research and Development Corporation
HDPE	High Density Polyethylene
HPP	High Pressure Processing
HS	Hermetic Storage
IIFS	Integrated Intensive Farming System
IFJ	Investing for Food and Jobs
ICAR	Indian Council of Agricultural Research
ICAR-CIPHET	ICAR-Central Institute of Post-Harvest Engineering and Technology
IR	Infrared
IQF	Individually Quick-Frozen
MA	Modified Atmosphere
MACS	Meeting of Agricultural Chief Scientists
MAP	Modified Atmosphere Packaging

MAP Storage	Modified Atmosphere Packaging and Storage
MB	Methyl Bromide
1-MCP	1-Methylcycopropene
MHA	Million Hectares
MIS	Market Information Service
MVP	Moderate Vacuum Packaging
MW	Microwave
NDCs	Nationally Determined Contributions
NABCONS	National Bank for Agriculture and Rural Development (NABARD) Consultancy Services
NEA	National Environment Agency
NGOs	Non-Governmental Organizations
PAYT	Pay-As-You-Throw
PEF	Pulsed Electric Field
PHL	Post-Harvest Loss
PICS	Purdue Improved Crop Storage Bags
PLW	Physiological Loss in Waste
PUF	Polyurethane
R & D	Research and Development
R&T	Roots and Tubers
SOP	Standard Operating Procedures
SSA	Sub-Saharan Africa
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
VAT	Value Added Tax
WFLO	World Food Logistics Organization
WRAP	Waste and Resource Action Programme
ZECC	Zero Energy Cool Chamber

1. INTRODUCTION

The world human population may become 9.7 billion in 2050, posing a major challenge to global food security apprehension. This population increase tantamount to a demand from additional 33% population of the world. Thus, the food supplies should increase by 60% to fulfil this demand in 2050 as estimated by Alexandratos & Bruinsma (2012). This ever-increasing human population throughout the world, particularly in the resource-poor countries, is posing serious challenge to provide safe and quality food to the masses. Increasing agricultural production along with proper distribution through technological interventions is one way to meet the additional food demand but this has some limitations too. Delivering food to the consumers by saving produced commodities from losses in fields, transport, storage, retailing, processing etc. without straining the fields, water and environment is another aspect. Further, non-consumption or throwing away the food after processing and value addition creates serious social, economic, food-safety and environmental concerns. Therefore, the slogan of **"A grain saved is a grain produced"** is an apt idea.

Food supply chain, handling and marketing system is a chain of interconnected activities from the time of harvest to the delivery of the food to the consumers. The primary role of an effective post-harvest system is to ensure that the harvested food reaches the consumer, while fulfilling customer satisfaction in terms of quality, volume and safety. Losses may be aggravated by an ineffective post-harvest system, which may include poor infrastructure, harvesting methods, post-harvest handling procedures, distribution, sales and marketing policies (World Bank, 2011).

The losses incurred at each step of post-harvest chain vary depending upon the machinery and technologies used. **In less developed countries**, larger losses are incurred in early and middle stages of food supply chain i.e., during harvesting, threshing/sorting, drying, storage, processing and in transportation due to low production volume from a single point and less mechanized supply chain (FAO, 2011). The major physiological, physical and environmental causes of post-harvest losses are high crop perishability; mechanical damage; excessive exposure to high ambient temperature, relative humidity and rain; contamination by spoilage fungi and bacteria; invasion by birds, rodents, insects and other pests; and inappropriate handling, storage and processing techniques (World Bank, 2011).

Food losses in the **developed countries** are generally low in the middle stages of the supply chain. This can be attributed to more-efficient farming systems, better transport, better management, storage, and processing facilities which ensure that a larger proportion of harvested output is delivered to the markets (Hodges et al., 2011). However, it is a cruel fact that in industrialized countries, significant waste occurs at the consumption stage with higher expenditure on transportation (FAO, 2011).

Peculiarly, current values related to post-harvest losses (PHLs) are not much different than the values cited earlier. As early as 1974, the first world food conference identified reduction of PHLs as part of the solution in addressing world hunger. At present the PHLs and food waste (FW) is about 30% and some extensive studies suggested that about 15% of grain may be lost in the post-harvest system (FAO, 2019). However, in India, the PHL of food grains was 4-9% in 2015 (Jha et al., 2015).

This paper presents the global scenario of PHLs and FWs, methodologies adopted to estimate losses, and recent advancements and technologies to reduce the PHLs and FW.

2. DEFINITION OF POST-HARVEST LOSS (PHL) AND FOOD WASTE (FW)

PHL and FW are defined as the measurable reduction in agricultural and livestock produce intended for human consumption (FAO, 2011). Food produced for animal feed, and non-food industrial uses are not the part of PHL. The PHL encompasses the quantity of food material diverted for feed/industrial use due to quality deterioration during handling and storage.

PHL and FW may be qualitative as well as quantitative in nature. Quantitative and qualitative losses are defined differently for different commodities in which several factors are considered. Some specific definitions of the losses are given below:

2.1Quantitative Loss (Loss in Weight)

A reduction of the physical substance of the food product is evidenced by a loss in weight and termed as quantitative loss (Nanda et al., 2012). However, there is a distinct difference between weight loss and loss of product. Decrease or increase in weight of food grains and other non-perishable commodities due to moisture absorption/desorption is not PHL. However, in horticultural and other perishable produce, the decrease in moisture content is considered as physiological loss in weight (PLW), and it affects quality of the produce also. Therefore, the PLW is considered as PHL in such commodities. Weight losses occur at any stage of food-supply chain due to shattering in the field, damage during plucking, spillage loss, PLW of horticultural/perishable produce, microbial/fungal attack, insect/pest attack, and losses during processing are the part of quantitative loss.

2.2 Qualitative Loss

Qualitative PHL are difficult to quantify and include inferior nutritional value, food-borne health hazards, goodwill loss, vigour loss, and economic losses (FAO, 2011; Nanda et al., 2012). Such qualitative losses may occur due to improper harvesting; improper primary processing; poor handling, inefficient transportation and distribution, poor storage management, during processing due to inefficient technologies and demand driven market forces (Jha et al., 2015). Reduction in the market value of the produce due to poor quality of the produce is considered as **qualitative loss**, however, fluctuations in the market prices due to demand and supply is not qualitative loss. The qualitative loss also depends on perception of the consumers which is likely to be influenced by time, place, cultural ethos and economic conditions.

Losses due to change in food qualities, such as alteration of the organoleptic features (aspect, taste, smell), presence of toxins, pesticide residues, etc., and decline in nutritive value are also considered under quality loss. Loss of germination/vigour is considered as qualitative loss, particularly in the grains, when it is intended for seed purpose.

2.3 Food Waste (FW)

FW is entirely different from PHL that arises from not consuming the processed/prepared food within the stipulated safe life period or throwing away the food. **Food waste** is defined as the reduction in the quantity or quality of food resulting from decisions and actions by retailers, food services, and consumers (FAO, 2019). Another definition of **food waste** is "food that is of good quality and fit for human consumption but that does not get consumed because it is discarded-either before or after it spoils (Lipinski et al., 2013).

However, the definitions of FW are debatable because at municipality level edible as well as non-edible portions of commodities are considered as FW and many a times such wastes can cause of serious environmental and waste management issues in the urban areas of the world. A separate term, for example **"non-edible agricultural and livestock by-products"** may be given and its quantum may be estimated to understand their impact.

METHODOLOGY TO ASSESS HARVEST AND POST-HARVEST LOSSES IN DIFFERENT PARTS OF THE WORLD 3

Adoption of uniform and systematic methodology is important for generating reliable data to reflect the accurate scenario of PHLs at country level. A large number of studies on the extent of harvest and PHLs have been conducted adopting different procedures and methodologies. Food and Agriculture Organization (FAO) proposed detailed methodology for data collection on quantitative losses in different operations and channels for food grains. ICAR-Central Institute of Post-Harvest Engineering and Technology (ICAR-CIPHET), Ludhiana, India has also provided a sound methodology to assess harvest and PHLs of agricultural, horticultural, and livestock produce (Jha et al., 2015), and similar methodology has also been adopted by (NABARD Consultancy Services) NABCONS (2022). However, the methodology for estimating qualitative losses and FW is scarce.

3.1Quantitative Post-Harvest Loss Estimation

Some of the specific features of methodology to access the food loss are as below.

(i) Initial Point to obtain Production Figures of Commodities: The initial point of start to consider the production values should be defined first to assess the PHL and FW in a value chain, which are:

- Crops have reached full ripe stage and are ready for harvesting and plucking.
- Animals are reared on the farm/field and ready for slaughter.
- Milking from the udder.
- Aquaculture fish reached to the maturity stage in the pond and ready for catch.
- Marine/river/lake fish caught in the net.
- In case of multiple plucking (for example harvesting vegetables), cumulative production is considered.

Losses occurring due to natural calamities, disease break-out in the standing crop or stored produce should not be taken into account for PHL and FW estimation.

(ii) Definitions of Field/Orchard/Herd/Pond for Data Collection: In general, the losses taking place in the kitchen gardens, backyard poultry, small ponds of fish for own consumption, animals reared for own consumption, etc. are not considered as PHL. The food grown for the general commercial sale for food purpose is considered to estimate the losses. A minimum area of a field/plants/herd has to be defined for on-farm loss estimation. These definitions include:

- A minimum piece of land for one field crop must have a size at least 1000 m^2 so that at least three random plots of 5×5 m (for plain region) or 2×10 m (for hilly terrains) can be selected for recording the losses by observation method.
- A cluster of minimum 12 fruit bearing trees of a particular crop on a single piece of land is defined as orchard for estimating the PHLs in horticultural/plantation crops and spices (Jha et al., 2015).
- A pond and other water bodies used to rear fish for sale in the market for food purpose.
- A poultry unit to rear birds for commercial egg or meat production.
- A herd of minimum 5 milch animals.

(iii) Storage Points: All kinds of storage of produce in the food supply chain are considered for the estimation of PHLs. The points of storages may be clustered in different groups, such as farm/household, warehouse/silo, wholesaler, retailer, processing unit, etc. The most important point to be considered to estimate the storage losses is the wholeness of commodity. PHL is limited to the point where the form of commodity has not been changed through processing and value addition. The loss incurred during storage of raw commodity in a processing unit is PHL whereas the losses taking place during processing operations, such as size reduction, crushing, peeling, etc., come under processing losses.

(iv) Data Collection Process: PHL estimation can be done by enquiry through personal interviews of the respondents, and by recording actual observation in the field/operations. Combination of both the processes is better from accuracy, data handling, and management point of view. The points to be considered for data collection are as follows:

- Identify the geographical area for the PHL data collection and crops/commodities for which data has to be collected.
- The unit operations, in which the possibility of losses is expected, should be identified carefully for each crop/commodity.
- Respondents for each operation should be identified.
- Stratified multistage random sampling method is a good option to select the respondents. The geographical area should be divided into different zones based on climatic conditions, soil, etc. (e.g. group of agro-climatic zones) - called strata. Each stratum is again divided into units (e.g. districts in the agro-climatic zone) which are taken as first stage sampling unit, division of first unit (e.g. blocks in a district) as second stage sampling units, sub-division of second stage unit (e.g. villages) as third stage sampling units and farmers as fourth stage sampling units.
- It is essential to cover at least 10% units of first stage sampling i.e. 10% districts in a strata. The number of first stage units in each stratum is taken proportionately rounded off to the nearest integer. The crops for different stratum may be allotted according to the production of crops/livestock produce. Major crops of the region are first allotted to the stratum. Thereafter, selected crops having lesser area in the zone may be added so that the effect of socio-economic and technological factors could be minimized and complete coverage of the area may be obtained.
- The number of respondents for each unit operation for each crop should be finalized using standard statistical tools and procedures. Similarly, the number of field, storage units, processing units, etc. for data collection in each strata must be finalized prior to the initiating the study.

(v) Data Recording Forms: Designing of the loss assessment form to collect all relevant information is critical, which may be required at the time of analysing the data. Different forms for each crop should be developed to collect the data by enquiry and by observation. These forms should be tested in the field and then modified. Some of the model survey forms may be consulted. The first form should be for the complete enumeration of the selected micro locations (e.g., villages, market, cluster of processing units, etc.) to collect basic information of the unit and random selection of respondents. Separate forms for data collection of PHL in farm operation, storage, processing losses etc. should be developed. The forms for data collection by observation should be prepared separately/common for each crop/commodity. The commodities may be grouped as per FAOSTAT's Food Balance Sheets (FAO 2011) as given below:

Table 1: Commodity Group as per Food Balance Sheet (FBS)

Commodity Group	Name of Commodities
Cereals (excl. Beer)	Wheat, Rice (Milled), Barley, Maize, Rye, Oats, Millet, Sorghum, Other Cereals
Roots and Tubers	Potatoes,Sweet Patato, Cassava, Yams, Other Roots
Oilseeds and Pulses (incl. Nuts)	Soybeans, Groundnuts (Shelled), Sunflower Seeds, Rape and Mustard Seed, Cottonseed, Coconuts (Incl. Copra), Sesame Seed, Palm Kernels, Olives, Other Oil Crops
Fruits and Vegetables	Oranges and Mandarins, Lemons and Limes, Grapefruit, Other Citrus, Bananas, Plantains, Apples (Excl. Cider), Pineapples, Dates, Grapes (Excl. Wine), Other Fruit, Tomato, Onions, Other Vegetables
Meat	Bovine Meat, Mutton/Goat Meat, Pig Meat, Poultry Meat, Other Meat, Offal
Fish and Seafood	Freshwater Fish, Demersal Fish, Pelagic Fish, Other Marine Fish, Crustaceans, Other Molluscs, Cephalopods, Other Aquatic Products, Aquatic Mammal Meat, Other Aquatic Animals, Aquatic Plants
Milk and Egg	The amount of Milk available for human consumption as Milk (but not as Butter, Cheese or Any Other Milk Product provided for separately in the FBS) and Eggs

Source: FAO (2011)

(vi) Data Analysis: The data collected during the survey should be digitized, further scrutinized for any discrepancies and errors during data entry. The analysis of data may be done using any statistical software. Appropriate statistical tools should be used to estimate the quantity handled and loss obtained. In order to estimate the overall total loss in a crop/livestock produce, the quantity of crop/ commodity retention/handling in each operation and channels during storage should be collected separately through a small survey and taking opinion of experts from each stratum. Since, the total produce obtained after harvesting operation is handled in each of the post-harvest operations at farm level, the total loss of a crop/ livestock produce in all the farm operations is taken as arithmetic sum of losses obtained for each individual operation. To estimate the total loss during storage in different marketing channels, data of percent retention in each market channel are required and weighted mean should be reported as loss .

3.2 Qualitative Food Loss Estimation

Qualitative loss is quite difficult to quantify because these losses overlap with the quantitative losses and arithmetic sum of different types of qualitative losses cannot be done. However, some suggestive points are proposed to quantify the extent of qualitative losses:

- The initial point of start and end point (consumer or processing unit) for the data collection must be defined precisely for each commodity. The initial points of estimation may be the points indicated in the quantitative loss estimation method.
- The material already discarded or considered as quantitative loss should not be included in the production figure for qualitative loss estimation.
- Respondent selection and data collection methodologies may be similar to that of quantitative loss.
- Each kind of qualitative loss should be defined clearly before the start of data collection. For example, to estimate the loss of nutritive value, the nutritional composition of the freshly harvested commodity must be defined at the start of study considering varietal character and climatic conditions of the region.
- Difference in size, weight, shape, colour, texture etc. of fresh produce are the inherent characteristic of agricultural and livestock produce. The difference in the market values due to these characters should not be accounted as qualitative loss. Comparison should be made based on the initial values of these parameters for each grade separately.
- The difference in the initial point of quality and final quality of the produce should be taken as qualitative loss. Summing the qualitative losses in each operation will lead to exaggerated value of losses. Weighted figure in the value chain should be considered.
- The quantum of qualitative losses is interrelated also. For example, nutritive value loss may be the reason of vigour loss. Such points should be taken care of while defining and estimating the qualitative loss.
- Loss of minerals and vitamins due to cooking/processing is usually termed as nutritional loss. However, cooking has a beneficial effect on digestibility of the commodity also. Such points must be considered while preparing methodology.

3.3 Processing Loss Estimation

For the estimation of losses during processing, the theoretical recovery of edible produce for human consumption from a commodity should be the initial production value. Each component of the processing operation should be defined to estimate the processing losses. Some suggestive points that are proposed to quantify the extent of processing losses are as follows:

- The initial point of start for the data collection should be the estimation of proportional quantity of produce going for the preparation of a specific product from the whole raw material production. For example, all the groundnut pods production does not go for oil expelling using expellers. The unit operations involved in oil expelling are decortication, oil expelling using expeller, deoiled cake stored in the solvent extraction plants, remaining part of solvent extraction of oil remained in the cake, deoiled cake going for food uses in the other industries, etc. Thus, the quantum of production diverted for oil expelling (subtracting the husk quantity) will be the initial production value to estimate the theoretical oil recovery. The loss of oil present in the quantity lost during the decortication will be the loss in one processing operation i.e. decortication. In case a part of deoiled cake obtained after oil expelling is not diverted to the solvent extraction units, the quantum of oil that went with such quantity of cake, spillage, etc. will be the loss during expelling. The residual oil in the cake during solvent extraction from the part of cake diverted to solvent extraction unit will be the loss in solvent extraction of groundnut.

- Non-edible material must be subtracted from the theoretical recovery for estimating the processing loss.
- The group of industries on the basis of capacity, type of machinery used, capacity utilization, etc. must be defined precisely for each commodity.
- The material already discarded or considered as quantitative loss should not be included in the production figure for projecting the processing loss at national level.
- Respondent selection and data collection methodologies may be similar to that of quantitative loss.

3.4 Food Waste Estimation

Møller et al. (2014) reviewed the methods to estimate FW. These methods include actual weighing, through scanning, analysis of waste composition, recording the wastage through enquiry from the respondents, and mass balance calculations. To estimate FW following points should be considered :

- Consideration of mass of wasted material obtained after processing. Such estimation projects increase in material weight due to absorption of water or other ingredients. Appropriate mass-balance is essential by calculating the actual weight of raw produce used in food preparation.
- Wastage occurrence due to natural calamities, accidents, rejection of shipments because of international trade regulations, etc. should not be taken into account as FW.
- In case of raw produce, qualitative and quantitative losses prevail. FW of raw produce will be considered only when the raw produce of standard quality is thrown/destroyed intentionally.
- Defining the stages of the value chain for the commodity.
- Grouping the respondents according to the consumer class, type of food server, etc.
- The material already discarded or considered as quantitative/qualitative loss should not be included in the weight/volume production figure for FW estimation.
- Respondent selection and data collection methodologies may be similar to that of quantitative loss.
- The weight/volume handled by each respondent group should be determined initially. Summing the FW of each stage will lead to exaggerated value of waste. To estimate the total wastage, data of percent flow in each component of value chain are required and weighted average should be reported as waste.

The above methods may be used as guidelines for estimating the FLW. Thorough review should be done before finalizing the methods and analytical methods. A thorough review of methods to estimate the qualitative PHLs has been given by Kitinoja et al. (2018). Similarly, a thorough review for the methods to estimate FW is given by Møller et al. (2014).

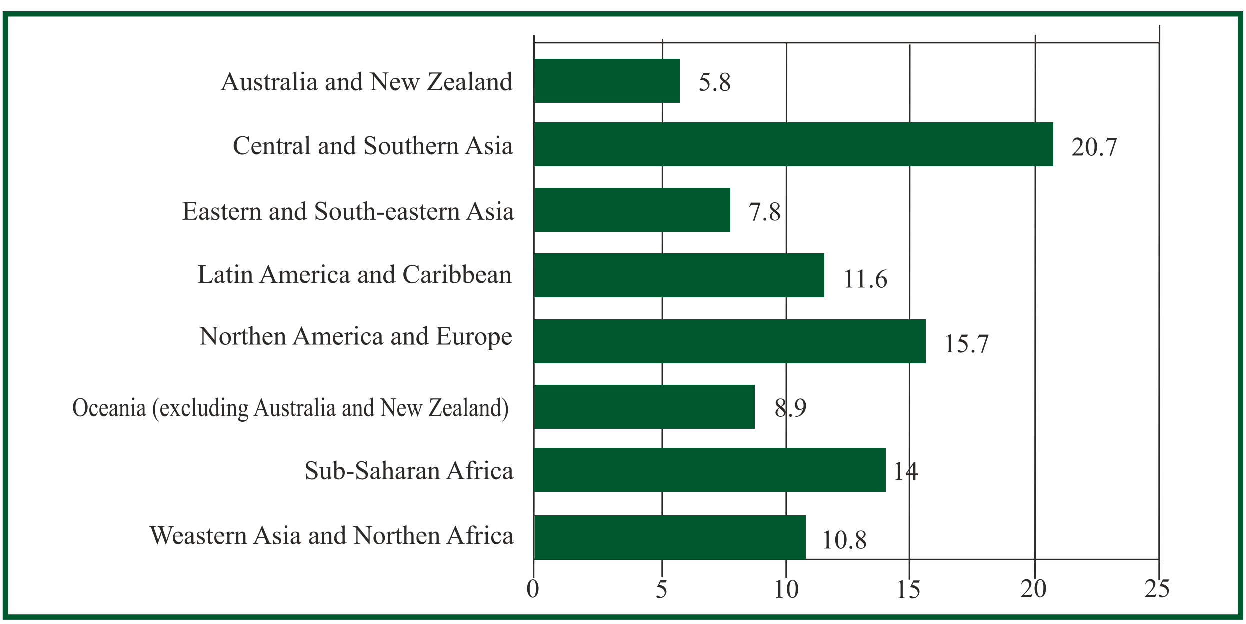
4. QUANTUM AND CAUSES OF POST-HARVEST LOSSES

4.1 Quantum of Food Loss and Waste

FAO has reported that globally about one-third of the food produced is either lost or wasted before consumption (FAO, 2011). This scenario is very serious in the Sub-Saharan Africa (SSA) where food losses are more prevalent and about 20% food grains, 44% roots and tubers, 52% fruits and vegetables (F&V) production are lost after harvest and before consumption (FAO, 2011). An estimated 95-115 kg of FW occurs per person annually in developed countries, such as Europe and North America. In contrast, one tenth of this level of consumer food waste- 6-11 kg per capita annually is generated within the low-income nations, especially Sub-Saharan Africa and South/Southeast Asia, (FAO, 2011). According to the World Resources Institute estimates, about 56% of the total world food loss and waste (FLW) took place in the developed world (USA, Oceania, Europe, and the industrialized Asian nations of China, Japan, and South Korea) whereas the developing world accounted for 44% of the loss and waste in 2009 (Lipinski et al., 2013).

Several international organizations are conducting studies on FLW. Some of these studies are comprehensive, however, majority of the studies are focused on estimating quantitative losses. Several reports have been published recently on the basis of secondary data analysis and estimated the FLW in different regions of world. As per the FAO report (2019), the food loss in different regions of the world is shown in **Figure 1.**

Figure 1: Status of Food Loss in Different Regions of World in 2016

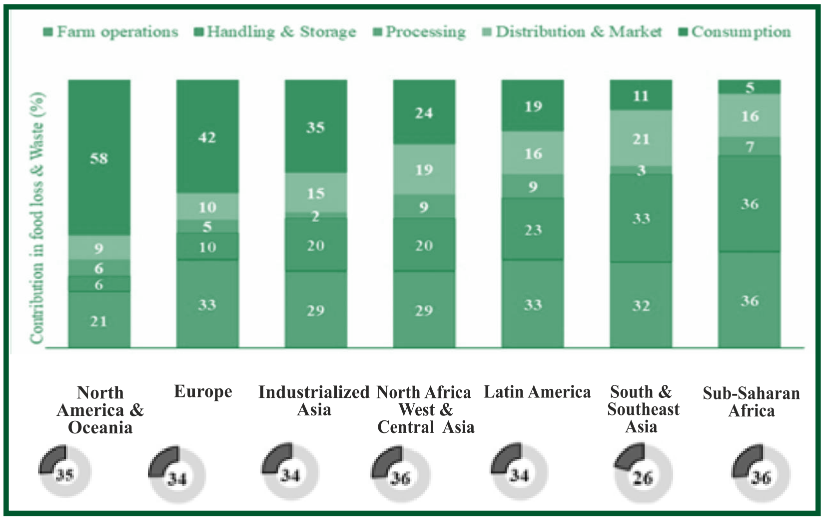


Note: Percentage of food loss refers to the physical quantity lost for different commodities divided by the amount produced. An economic weight is used to aggregate percentages at regional or commodity group levels, so that higher-value commodities carry more weight in loss estimation than lower-value ones.

Source: FAO, 2019

Flanagan et al. (2019) calculated the FLW in different components of value chain for different regions of the world on the basis of secondary data as shown in **Figure 2.**

Figure 2: Contribution of Value Chain Components in Food Loss and Waste for Different Regions of World, Pie Chart Shows the Total Loss (%) in the Region.



Source: Flanagan et al., 2019

4.2 Food Loss in Different Parts of the World

4.2.1 Developing Countries

4.2.1.1 Asia

Comprehensive study was conducted by Indian Council of Agricultural Research (ICAR) in 2012-15 to assess the extent of PHL for 45 crops and livestock produce in India. The study established that the losses were **4.65 to 5.99% in cereals, 6.36 to 8.41% in pulses, 3.08 to 9.96% in oilseeds, 6.7 to 15.88% in fruits, and 4.58 to 12.44% in vegetables**. The study also reported the PHL of plantation crops, spice crops, meat, milk, egg, poultry meat, inland fish and marine fish. The estimated annual value of the PHL in India were estimated to be ₹ 926.51 billion (US$ 15.9 billion) in 2014 (Jha et al. 2015). PHL has showed a declining trend in India and found to be 3.89-5.92% in cereals, 5.65-6.74% in pulses, 2.87-7.51% in oilseeds, 6.02-15.05% in fruits, 4.82-11.61% in vegetables, 3.72-7.33% in plantation crops, 1.20-6.11%in spices, 4.86% for inland fish, 8.76% for marine fish, 2.34% in meat, 5.63% poultry meat, 6.03% in egg, and 0.87% in milk. If the extent of losses recorded for 45 commodities in 2015 of Jha et al (2015) study continued, the monetary value of the loss would have been ₹1665.94 billion, whereas the estimated economic value loss for the same 45 commodities in 2022 by NABCONS (2022) study was ₹1461.53 billion. **Thus, the NABCONS (2022) study showed that the monetary loss was reduced by ₹204.41 billion (US$ 2.50 billion) annually in India due to the reduction of PHL**.

In other Asian countries, PHL studies are limited to a few crops, particularly fruits and vegetables (F&V). The studies on PHL in the Asian countries are summarized in **Table 2 (Page 20).**

The reported PHL in the Asian countries for F&V are more than 10%. However, the extent of PHL reported in **Table 2** for several Asian countries are not done in actual field conditions. Further, South Asia is known for the cultivation of spices, plantation crops, tropical fruits, and sugarcane, however the estimates of PHL for these crops are available only for India. A comprehensive systematic study on PHL in the Asian countries is required to understand the PHL in Asia to identify the issues and take curative measures.

Table 2: Crop-Wise Extent of Post-Harvest Losses in Different Asian Countries

S. No.	Name of Crop	Country Name	Post-Harvest Loss (%)	References
1	***Apple***	Bhutan	12.78	Rinchenz et al. (2019)
2	***Banana***	Sri Lanka *	28.80	FAO (2018a)
3	***Citrus***	Nepal*	20.29	FAO (2018a)
4	***Grapes***	Egypt*	45.76	FAO (2021a)
5	***Pineapple***	Bangladesh*	43.00	Hassan et al. (2010)
6	***Beans***	Sri Lanka	27.91	FAO (2018a)
7	***Brinjal***	Bangladesh	13.90	Khatun and Rahman (2019)
8	***Cabbage***	Philippines	26.50	Gonzales and Acedo (2016)
9	***Cauliflower***	Nepal*	18.30	FAO (2018a)
10	***Okra***	Bangladesh*	32.30	Molla et al. (2011)
11	***Milk***	Asia	2.20	FAO (2011)
12	***Egg***	Asia	8.00	Gustafsson et al.(2013)
13	***Meat***	Asia	5.60	FAO (2011)
14	***Inland Fish***	Bangladesh	7.01	Rashid and Sarkar (2020)
15	***Marine Fish***	Bangladesh	11.67	Rashid and Sarkar (2020)
		Asia	17.00	FAO (2011)
16	***Bajra***	Bangladesh	3.81	Molla et al. (2011)
17	***Wheat***	Korea*	16.35	FAO (2014)
18	***Black Gram***	Bangladesh	13.70	Mannan & Tarannum (2011)
19	***Cashew Nut***	Sri Lanka	15.00	Priyashantha et al. (2020)
20	***Sugarcane***	Pakistan*	27.80	Hussain et al. (2018)
21	***45 Crops and Livestock Produce***	India	4.58-15.88	Jha et al. (2015)

Limited area or laboratory studies and does not represent the PHL for the entire geography

Source: Compiled by Authors

4.2.1.2 Africa

As per the 'Missing Food' study conducted by African Postharvest Losses Information System (APHLIS), 13.5% of the cereal grain produced across Sub-Saharan Africa is lost, which is equivalent to US$4 billion per year or the annual calorific requirement of 48 million people (World Bank et al., 2011). The estimated average magnitudes of PHL in Ethiopia ranges from 15.5 to 27.2% for major food grains (Mohammad and Tadesse, 2018) and 23% average loss for all crops (MANR, 2018). The latest African Union 2020 Biennial Review Report on the implementation of the 2014 Malabo Declaration showed that only 19 countries out of 54 reported on PHLs. The average loss for main commodities were as: Benin (27.5%), Côte d'Ivoire (31.9%), Nigeria (26.4%), Togo (21.4%) and Sierra Leone (46.1%).

The extent of PHL reported in the literature for different African countries is given in **Table 3 (Page 21)**.

Majority of the studies reported in Table 3 are focused on major crops of that country and some of the studies were limited to single unit operation only. The PHL was studied systematically in Ghana by FAO (FAO, 2010), whereas other studies were focused on the major single crop of the country. For cassava, 8.5% PHL at farm level and 12.1% PHL at the processing level were reported in Nigeria (Oguntade, 2013). For maize, 3.5% PHL at the farm level and 26.6% PHL at the retail level was reported in Nigeria (GIZ, 2013). Overall PHL for tomatoes (56%) and for green chillies (7%) in Rwanda has been reported (Musanase and Kitinoja, 2017; Chahine-Tsouvalakis et al., 2017). However, in Ghana, such high losses were not observed owing to systematic study conducted by the FAO. Thus the systematic study of PHL is essential to understand the extent of PHL in African countries.

Table 3: Extent of Post-Harvest Losses in African Countries

S. No.	Name of Crop	Country Name	Post-Harvest Loss (%)	References
1	***Grapes***	South Africa	5.97	Blanckenberg et al. (2021)
2	***Guava***	North-Western Ethiopia	16	Muluken et al. (2017)
3	***Mango***	Ghana	13.36	Kitinoja and Cantwell (2010)
		Republic of Guyana	28	FAO (2018b)
		Eastern Caribbean Island	23	FAO (2018c)
4	***Muskmelon***	Ethiopia	16.7	Kitinoja and Kader (2015)
5	***Papaya***	Ethiopia	5.5	Seid et al. (2013)
6	***Pomegranate***	South Africa	6.74-7.69 (Packhouse)	Opara et al.(2021)
7	***Okra***	Ghana	24.2	Ridolfi et al. (2018)
8	***Onion***	Ghana	13.5	FAO (2010)
9	***Tapioca***	Nigeria	13	Bamikole et al. (2022)
10	***Tomato***	Trinidad & Tobago	28	FAO (2018d)
		Guyana	17	FAO (2018e)
11	***Milk***	Ethiopia	6.5	Minten et al. (2019)
12	***Egg***	Africa	8	Gustafsson et al. (2013)
		Ghana	12	FAO (2010)
13	***Meat***	Ghana	14	
14	***Poultry Meat***	Ghana	4	
15	***Inland Fish***	Ghana	21.93	
16	***Marine Fish***	Ghana	21.08	
		Kenya	1-2 (drying)	FAO (2014)
17	***Paddy***	Timor-Leste	23.5	FAO (2018f)
		Congo	13	FAO, IFAD and WFP (2021)
		Ghana	13.5	Ridolfi et al. (2018)
18	***Maize***	Zimbabwe	14.10	FAO (2020)
19	***Chickpea***	Ethiopia	4.51	Chichaybelu (2014)
20	***Pigeon pea***	Tanzania	10.2	Abass et al. (2014)
21	***Groundnut***	Zimbabwe	21.8	FAO (2020)
22	***Sunflower***	Uganda	9.90	FAO, WFP & IFAD (2021)
23	***Coconut***	Tanzania	17.50	Punchihewa and Arancon (1999)

Source: NABCONS, 2022

4.2.2 Developed Countries

4.2.2.1 North America, Europe, Australia

Estimates by FAO (2011) reported food loss in North-America and Europe as 280-300 kg/year per capita, whereas the total per capita production of edible portion of human food was about 900 kg/year, which indicated that the PHL was about 31%. In North America (USA, Canada, and Mexico), annual PHL and FW amounted to 168 MT (Mesterházy et al. 2019). About 40% of the annual US food supply is lost and wasted. However, the studies on PHL in developed countries are limited because of complex structure of food, feed, and industrial uses of the agricultural and livestock produce. PHL of some of the commodities in the developed countries are reported in **Table 4.**

High values of losses reported in Table 4 for the developed countries do not represent the actual PHL because of high and strict quality standards and diversion of medium to low quality produce for various commercial products preparations. However, study on PHL in the developed countries should also be done keeping the quality parameters in picture.

Table 4: Estimates of Post-Harvest Losses in North American and European Countries

S. No.	Name of Crop	Country name	Post-Harvest Loss (%)	References
1	***Guava***	Brazil	Groceries Stores – 17 Supermarkets – 21	Mendes et al. (2019)
2	***Papaya***	Brazil	17.9	De Sousa Ferreira et al. (2020)
3	***Onion***	United Kingdom	Farm: 3-5, Grading: 9-20, Storage: 3-10, Packing: 2-3	Porat et al. (2018)
4	***Milk***	Europe	5.2	FAO (2011)
		North America	5.2	
5	***Capsicum***	Brazil	33.33	Dos Santos et al. (2020)
6	***Meat***	Europe	0.7	FAO (2011)
		North America	1	
7	***Poultry Meat***	USA	4	Buzby et al. (2014)
8	***Inland Fish***	Europe	9.9	FAO (2011)
9	***Marine Fish***	North America	12.5	
		Latin America	10.7	
10	***Soybean***	Europe	6	Fine et al. (2015)
11	***Safflower***	Australia	3-4	GRDC (2017)

Source: NABCONS, 2022

4.3 Qualitative Losses

Only a few studies include information on nutritional losses and reported PHLs in terms of nutrition or calories. Maize has a food value of 3700 kcal/kg, which means that the loss in food value is a minimum of 1.04 trillion kcal annually in Nigeria (Kitinoja et al., 2016). This amount could have fed 1.14 million persons for a full year @2500 kcal/day. Sweet potatoes have a food value of 860 kcal/kg and its PHL in Nigeria potatoes is approximately 59.34 billion kcal annually that could have fed 65,000 persons for whole year (Kitinoja et al., 2016). Cassava has a food value of 1,600 kcal/kg. The losses in food value, at a minimum, equals approximately 14.4 trillion kcal in Nigeria. This could feed 15.78 million persons for a full year (10% of Nigeria's population).

Tomatoes are a relatively low-calorie food, with a food value of only 180 kcal/kg, but they also contain many nutrients such as vitamins and minerals. The vitamin C content of red ripe tomatoes is about 180 mg per kg, supplying enough of the daily requirement of vitamin C for two to three adults. The loss in food value due to PHLs of 15 to 20% reported for tomatoes in Egypt (Kitinoja et al., 2016), is the equivalent of approximately 230.4 billion kcal.

Vitamin C losses were reported for okra in processing and storage of dried products in Ghana (Tekpor, 2011). Solar drying resulted in 52.5 to 60.7% loss in vitamin C, and the stage of maturity at harvest and the drying time affected the level of losses. Okra harvested at 6 days after setting (proper maturity) lost comparatively more vitamin C than those harvested at 4 days after setting (immature). Okra dried for 48 hours had more vitamin C loss than okra dried for 24 hours, but slice size did not affect vitamin C content.

All the above studies are the projections on the basis of assumptions and calculations made from the reported PHL values. However, production of a crop comes for a limited time in a year and ensuring round-the-year supply of perishables is possible through storage, processing, and value addition. Therefore, such loss of nutritive value is of academic importance only. Systematic methodology to estimate the qualitative losses, which is acceptable to peer groups, is not found in the literature.

4.4 Food Waste (FW)

According to the Flanagan et al. (2019), FW in the value chain for different regions of the world on the basis of secondary data is shown in **Figure 3 (Page 24)** .

When **Figures 2 and 3** are analysed together, the FL occur at the production phase and found to be homogenous across regions. However, FW varied widely across the regions. Further, the FAO report (2011) suggested that about 33% of the global food production was lost or wasted, which is equivalent to 1.3 billion tonnes of produce per year. **Figure 2 (Page 19)** suggests that the FW occurring at consumption level are highly variable and it was higher in the middle and high-income regions (12-21%), but it was much less in low-income regions (1-9%). This may be due to the fact that economically stronger countries have stringent quality standards and consumer sensitivity. Also these societies strictly follow the discarding protocols and practices for the food not considered fit for human consumption past the printed expiry date on the package.

However, United Nations Environment Programme (UNEP, 2021) Food Waste Index Report is showing the higher FW in low income regions as given in **Table 5.**

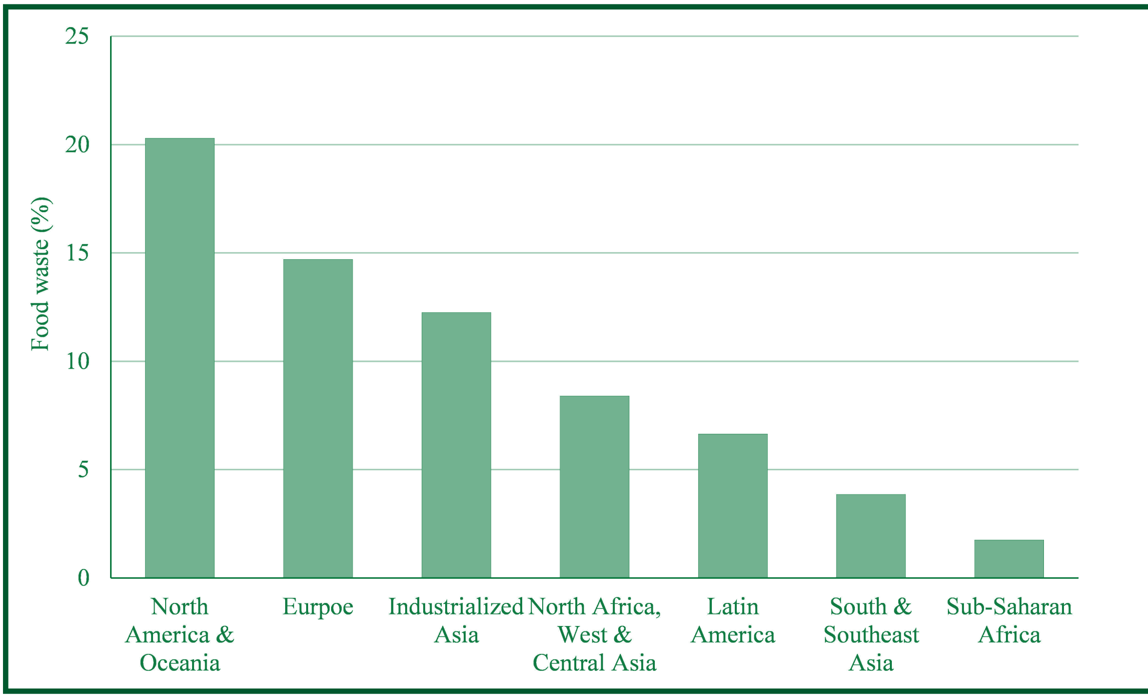
The UNEP (2021) estimates are based on the published work in the last decade and high confidence studies were considered to project the FW. It may be observed that the household level waste was higher in the low-income countries. Further, only one study (Miezah et al., 2015) of

Table 5: Average Food Waste (kg/capita/year) as per World Bank Income Classification

Income Group	Average Food Waste (kg/capita/year)		
	Household	Food Service	Retail
High-Income Countries	79	26	13
Upper Middle-Income Countries	76	Insufficient Data	
Lower Middle-Income Countries	91	Insufficient Data	
Low-Income Countries	Insufficient Data		

Source: UNEP Food Wastage Index, 2021

Figure 3: Estimated Food Wastes in Different Regions of the World



Source: Flanagan et al., 2019

Ghana was considered by the UNEP as high confidence for the purposes of the Food Waste Index in low-income countries, which showed FW as 84 kg/capita/year. Hence, UNEP (2021) concluded that the household per capita FW generation was broadly similar across country income groups. This conclusion diverges from earlier narratives that the consumer level FW was high in developed countries whereas high losses took place at food production, storage and transportation levels in developing countries. Further, UNEP (2021) concluded that the FW at consumer level (household and food service) was more than twice that of previous FAO estimate in 2011 though the data were insufficient on the edible fraction of food waste to allow comparative analysis across country income groups. The report estimated that around 931 MT FW was generated in 2019, out of which 61% was households waste, 26% in food service and 13% was accounted for retail services. This report further suggests that 17% of total global food production is wasted (11% in households, 5% in food service and 2% in retail).The estimated FW by UNEP (2021) might be appropriate to understand the proportion of FW in the wastes generated in the cities, however, not conclusive. Food procurement, preparation, supply chain, consumption, etc. are different in the developing and developed countries and hence the FW values will vary. For example, fruits contain about 15-50% non-edible parts and only 6-8% of the total fruit production of India is processed whereas remaining produce is purchased by the consumers for household consumption. In contrast, consumers of USA procure fruit juices at their households. Thus, the location of non-edible waste generation are at processing units in developed countries whereas FW is generated at the household level in developing countries, which is not reflected in the UNEP (2021) report. Further, the calculations of FW by UNEP (2021) are based on the mass of processed food, which may not be accurate, particularly in case of cereals, where mass of FW was taken as wet mass wastage. For example, mass of rice becomes about four times after cooking and any FW calculation on the basis of cooked rice mass may escalate - FW estimate four times than the actual value.

In addition to the above-mentioned FW estimates, **Table 6 (Page 25)** reports the global and country-specific estimated FW / FLW quantities and shows the diversity in the scale, scope, and quantification of these methods.

Comparison of FW in different countries reported in **Table 6** is difficult because some of these studies include PHL and FW whereas some are focussed on FW only. For example, in England, Department for Environment, Food and Rural Affairs (2010) estimated 16% food purchases as FW whereas Waste and Resource Action Programme (WRAP) study shows FW of 4.2 MT because both the studies have used different methodologies for estimation (DEFRA, 2010). Further, in many of these studies, the FW values are based on municipal waste analysis. Therefore, a uniform estimation method for FW is required. Some of the studies aimed to develop methods for FW quantification (Östergren et al., 2014; Thyberg et al., 2015). The studies on extent of FW done by Japan showed that Japan has progressed much in reducing the FW and in one decade the waste has been reduced from 37.86 MT in 2011 to 5.23 MT in 2021.

Table 6: Estimated Quantities of FW/ FLW by Geographical Area

Area	Type	Amount	Reference
Global	FLW	614 kcal/person/day	Kummu et al. (2012)
Global	FLW	1.6 billion tonnes annually	FAO (2013)
Australia	FLW	4.06 MTs annually	Ridoutt (2010)
China	FLW	70% part is FLW of total municipal solid waste (MSW)	Xin et al. (2018)
China	FW	90 MTs (51% of MSW)	Wen (2016)
Denmark	FLW	700,000 tonnes annually	Pärn (2016)
England	FW	16% of edible calories or 15% of edible drink and food purchases	Department for Environment, Food & Rural Affairs (2010)
Finland	FW	23 kg/person/year	Koivupro et al (2012)
Italy	FW	40,000 tonnes annually	Cicatiello et al. (2016)
Japan	FLW	37.86 MT in 2011	Liu et al (2016)
New Zealand	FW	148 kg/household/year	WasteMinz (2015)
Nordic Countries	FLW	40,000–83,000 tonnes annually	Stenmarck et al. (2011)
Singapore	FLW	809,800 tonnes in 2017	NEA (2018)
South Africa	FLW	177 kg/person annually	Oelosfe and Nahman (2013)
Switzerland	FLW	48% of total calories	Beretta et al. (2013)
United Kingdom	FW	4.2 MT annually	WRAP (2013)
United States	FW	34.69 MT annually	USEPA (201 4)
United States	FW	35.5 MT annually	Thyberg et al. (2015)
India	FW	50 kg/person/year	UNEP (2021)

**** FL: Food Loss; FW: Food Waste and FLW: Food Loss and Waste***

Source: Ishangulyyev et al., 2019

5. REASONS FOR FOOD LOSS AND WASTE

Agricultural produce undergo several operations, such as harvesting, threshing, cleaning, drying, storage, processing and transportation. Loss of produce takes place in each operation due to several factors such as improper handling, inefficient processing facilities, biodegradation due to microorganisms and insects etc. **The reasons of PHL and FW may be classified into primary, secondary and tertiary factors, which directly influence the total food supply chain.**

- **Primary factors** of losses include: genetic characteristics of produce, biological factors (insect infestations, rodents, microbes, birds etc.), physiological (respiration, ripening, dormancy), environmental (weather, temperature, humidity), farm operations (harvesting, threshing, grading/sorting, drying, packaging), storage infrastructure (methods of storage, warehouses, silos, cold-chains), and processing (traditional or advance processing facilities).
- **Secondary factors** include: ancillary services that support the movement of goods from farm gates to market and consumers (e.g. access to road network, transportation, and market information; cost of postharvest infrastructure and services; knowledge of handling) and consumer behaviour.
- **Tertiary factors** relate to external factors that directly impact on access and delivery of postharvest technologies and services (e.g. government policy and investments in agriculture, private sector participation and investments, advocacy groups and lobby in agriculture, etc.).

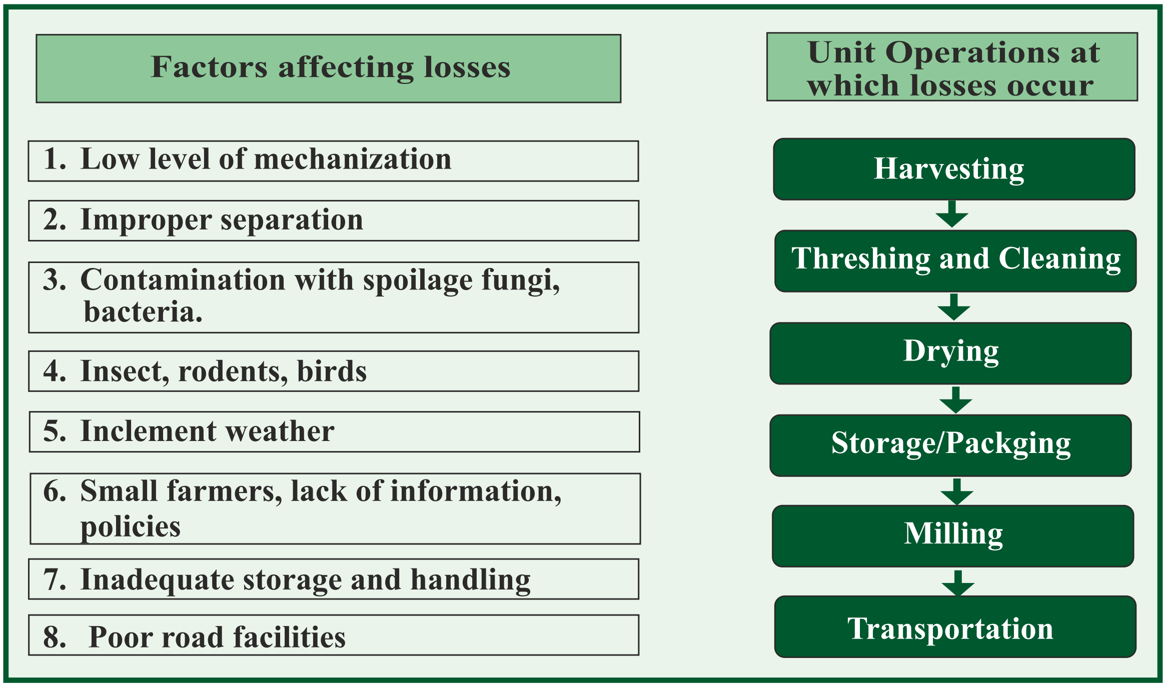
In horticultural crops the causes of PHLs can be divided into following categories:

- **Metabolic:** All fresh horticultural crops are live organs. The natural process of respiration involves the breakdown of food reserves and the aging of these organs.
- **Mechanical:** Owing to their tender texture and high moisture content, fresh F&V are very susceptible to mechanical injury. Poor handling, unsuitable containers, improper packaging and transportation can easily cause bruising, cutting, breaking, impact wounding and other forms of injury.
- **Developmental:** These include sprouting, rooting, seed germination, which lead to deterioration in quality and nutritional value.
- **Parasitic Diseases:** High PHLs are caused by the invasion of fungi, bacteria, insects and other organisms. Micro-organisms attack fresh produce easily and spread quickly, because the produce does not have much of a natural defence mechanism and has plenty of nutrients and moisture to support microbial growth.
- **Physiological Deterioration:** F&V cells remain alive after harvest and continue their physiological activity. Physiological disorders may occur due to mineral deficiency, low or high temperature injury or undesirable atmospheric conditions, such as high humidity. Physiological deterioration can also occur spontaneously by enzymatic action leading to over-ripeness and senescence, a simple aging phenomenon.
- **Lack of Market Demand:** Poor planning, inaccurate production and market information may lead to over production of certain F&V which cannot be sold in time. This situation occurs frequently in areas where transportation and storage facilities are inadequate. Produce may lie rotting in production areas, if farmers are unable to transport it to people who need it in distant locations.
- **Consumption:** These losses can be due to inadequate preservation methods at home, methods of cooking and preparation such as peeling, consumption styles etc.
- **Others:** Lack of clear concept of packing house operations; Lack of infrastructure; Inadequate technical support; Wide gap in technologies available and in vogue; Inadequate post-harvest quality control; Unorganized marketing; Absence of pre-cooling and cold storage; Inadequate market facilities; market intelligence and market information service (MIS).

5.1 Reason of Losses in Food Grains

The factors and type of losses in various operations of supply chain of food grains in developing countries is depicted in **Figure 4.**

Figure 4: Various Factors and Types of Losses during the Supply Chain of Cereal Crops in Developing Countries



Source: Compiled by Authors

5.1.1 Harvesting

Harvesting is the first critical step in the grain supply chain, which decides the overall crop quality. In the lesser developed countries, harvesting is performed manually using hand cutting tools such as sickle, knife, scythe, cutters. Almost all of the crop is harvested using combine harvesters in the developed countries. Harvest timing and method (mechanical vs. manual) are two critical factors that dictate the losses. A large amount of losses occurs before or during the harvesting operations, if it is not performed at adequate crop maturity and moisture content (Vishwakarma et al., 2020). Too early harvesting of crop at high moisture content increases the drying cost, making it susceptible to mold growth, insect infestation, and resulting in a high amount of broken grains and low milling yields. However, leaving the matured crop un-harvested results in high shattering losses, exposure to birds and rodents attack and losses due to natural calamities (rain, hailstorms etc.).

5.1.2 Threshing

The purpose of the threshing process is to detach the grain from the panicles, which is done through rubbing, stripping, or impact action, or using a combination of these actions. Manual threshing is the common practice in the low-income countries. Grain spillage, incomplete separation of the grain from chaff, and breakage due of excessive striking are the major reasons for losses during the threshing. Delay in threshing results in significant quantity and quality loss, as the crop is exposed to atmosphere and is susceptible to rodents, birds, and insect attack. Lack of mechanization is the major reason for delay in threshing. High moisture accumulations in the crop lying in the field may even lead to mold growth.

5.1.3 Cleaning

Cleaning is performed after threshing to separate whole grains from broken grains and other foreign materials, such as straw, stones, sand, chaff, and weed seed. Winnowing is the most common method used for cleaning in the developing countries. Screening/sifting is another common method of cleaning, which can be performed either manually or mechanically. Inadequate cleaned grains can increase the insect infestation and mold growth during storage, add unwanted taste and colour.

5.1.4 Drying

The safe moisture content for long-duration storage of most of the food grains is considered below 13%. Even for the short-term storage (less than 6 months), the moisture should be less than 15%. Inadequate drying causes mold growth and significantly high losses during storage and milling. Sun drying is the preferred method in developing countries, which is weather dependent, requires high labour, slow, and causes losses. Grains lying in the open for sun drying are eaten by birds and insects, and also get contaminated due to mixing of stones, dust, and other foreign materials. Some farmers in low-income countries use mats or plastic sheets for spreading the grains, which reduces the contamination with dust and makes the collection of grains easy. Mechanical drying addresses some of the limitations of natural drying, and offers advantages, such as reduction in handling losses, better control over the hot air temperature, and space utilization. However, they suffer with the limitations of high initial and maintenance cost, adequate size availability, and operational skill especially with smallholders.

5.1.5 Storage

Storage plays a vital role in the food supply chain, and high losses can take place if not maintained properly. The indigenous storage structures are used in the low income countries that are made from locally available materials (grass, wood, mud etc.) without any scientific design, and cannot guarantee to protect crops against pests for a long time. Improved storage structures include silos, warehouses, cocoons and hermetic storage structures that reduce losses significantly.

5.1.6 Transportation

Transportation is an important operation of the grain value chain to move the commodity from one place to other. The lack of adequate transportation infrastructure results in damage of food products and losses due to spillage. At the field level, most of the crop was transported in bullock carts or open trollies in South Asian countries. Poor road infrastructure along with improper and poorly maintained modes of transportation results in large spillage and high contamination. Multiple movements of crop is another major reason for high transportation cost and losses. Low quality Jute bags are used commonly during transportation and even storage, which results in high spillage rates due to leakage from the sacks. Bulk transportation facilities are lacking in the low income countries.

5.1.7 Milling

Milling or processing operations vary for different grains. The operation in low-income countries is performed manually or using small-capacity milling machines. Milling yields are highly dependent on the milling method, skills of the operator, and crop conditions before the milling process. Milling of paddy containing foreign materials results in a high amount of cracked and broken kernels and can also damage machines. Inadequately maintained milling machines result in a high amount of broken kernels and low milling yields. High moisture and an inadequately cleaned paddy aggravate the situation and reduce yields.

5.2 Specific Reasons for Food Loss and Waste in Developing and Developed Countries

The reasons of FLW also depend upon the mechanization level, farm size, cultural practices, and economic status of the countries. A comparison was made by Bond et al. (2013) to identify the reasons of losses in developing and developed world. This is given in **Table 7 (Page 29-30).**

Table 7: Typical Causes for Food Loss and Waste arising within Developing and Developed Countries

Developing Countries	Developed Countries
• **Land Holding and Production Pattern :** Small land holding, multi -cropping system, cultivation of many crops in each season on small farms results high loss. • **Pre-Harvest Losses:** Extreme weather, pests, disease and weeds, less resilient crop varieties, poor soil quality and water shortages. • **Agricultural Production:** weather effects, poor agricultural practices (e.g. tilling, continuous flood irrigation etc.). Technological limitations, often from manual farming with traditional implements, although increasingly with some level of crude • **Labour Limitations:** Many women and children farmers miss educational opportunities when working in the field. High incidences of ill-health (e.g. HIV/AIDS) can also lead to labour shortages, especially at peak harvesting times. • **High Animal Mortality Rates:** Poor animal welfare standards and high occurrence of disease (e.g. mastitis) which lowers productivity and potential market opportunities. • **Early Harvesting:** Forced through weather conditions, alleviating hunger and financial constraints. Early harvest results in lower nutritional foods and lower returns on selling goods. • **Post-Harvest Handling:** Inefficient use of traditional and crude processes, for example: threshing, drying and winnowing practices. Poor or non-existent transit packaging and staff training in pack houses, lead to increased rates of product damage (e.g. through the crushing and bruising or produce). • **Post-Harvest Storage:** Losses from spillage or spoilage (pests and diseases) and foraging losses by birds and rodents etc. • **Lack of Physical Infrastructure:** Especially important in harsh climates. Poor storage and distribution facilities including cold-chain apparatus. • **Processing Facilities:** Low number of processing facilities, which limits scale of produce to be processed (i.e. higher value-chain) and preserved (shelf-life extension). Inadequate storage facilities affect food supply chains and networks.	• **Land Holding and Crops:** Usually single crop in a year on very la rge forms, efficient mechanization, storage and distribution, lead to lower loss. • **Demand Forecasting:** Demand Forecasting at the retailer end and at the growing stage is inherently complex and inaccurate, affected by seasonality, weather, time lag in crop production, marketing campaigns, product launches and special occasions/events leading to highly unpredictable demand. Sales channels are also becoming increasingly complex (e.g. in-store and online sales). • **Pre-Harvest Losses:** Climate change is likely to increase the prevalence of severe weather and certain pests, disease and weeds in crop varieties and animal breeds which have been chosen for yield rather than resilience or resistance. • **Mechanization:** Losses attributed to farming practices and machine inefficiencies. • **Over-Production:** For farmers to meet contractual obligations, an excess in yield is forecast to serve as contingency – but may not reach market. • **Storage:** Losses from insects, microbial spoilage, shrinkage and storage failures (cold-chain, modified atmospheres etc.). • **High Retail Grading Standards:** Produce which does not meet strict quality standards relating to appearance, weight, size, colour and shape may be rejected, often being diverted as animal feed or even ploughed back into the ground. • **Food Trimming:** Excessive waste from automated or manual trimming. Additional processor errors. Processed food often requires additional packaging and assigned retailer date labels (unlike many unprocessed produce). • **Poor Handling:** Packaging failures, spillages, product damage, and cold-chain efficiencies. • **Supply-Chain:** Shrinkage, product recalls, packaging changes, labelling errors, cold-chain failures, contamination. • **Retailers:** Forecasting, out-grading standards, delivery rejections, poor stock rotation, promotions management.

Contd. to page 30

Developing Countries	Developed Countries
• **Market Networks:** Distribution and market networks (e.g. too few wholesale, supermarket and retail outlets). Transport infrastructure, power supply and storage infrastructure (e.g. cold chain) affect food supply chains, networks and waste levels. Further problems include, poor information exchange between growers and markets, lack of grading of what's sent to market, lack of price differentiation of quality, markets not functioning well for small holders, because of too many middlemen. • **Low Private Sector Investment:** Private sector has ability to provide sustained market access and supply-chain capabilities - including distribution, processing, preservation and market networks.	• **Fast-Food Time Limits:** Commercial outlets set 'standing' timelines after which cooked food must be discarded if not sold. These timelines can be short (e.g. 10-20 minutes). • **Consumers:** Affordability, attitudes, behaviours, choice, promotions, date labelling, food safety concerns, poor shelf life of fresh products after purchase. • **Household Practices:** Portion sizes, discarding leftovers, poor meal planning and cooking abilities, low awareness of food handling or safety and optimal storage (including correct storage options, refrigeration maintenance or freezing practices).

Source: Bond et al., 2013

Identification of the reason of PHL is critical and depends upon several interrelated factors. Some examples of identifying the exact reasons of PHL in the ICAR-CIPHET study in 2013-14 (Jha et al., 2015) are given below to create better understanding about the importance:

- **Apple is cultivated** in two states of India namely Jammu & Kashmir and Himachal Pradesh and unit operations were similar in both the states. However, in Himachal Pradesh, farmers initiated harvesting when truck arrived at the site. Workers plucked all the ripe and unripe fruits hurriedly to fill the truck. High loss (~5%) was observed in harvesting. Contrary to this, in Jammu & Kashmir, trucks were called after harvesting and apple remained in the field for 7-10 days. Grading and packaging were undertaken after truck's arrival. High loss (~5%) was found in grading operation. Based on this observation, ICAR-CIPHET study identified poor infrastructure as a reason for loss in apple and recommended improvement in infrastructure as a policy intervention.
- **Threshing of chickpea** was done using high-capacity wheat threshers, which caused mechanical damage. This was identified during cleaning operation. Therefore, use of crop specific threshers was recommended.
- **In Uttarakhand, F&V** were collected from the farmers by marking the identity of farmer and transported by the wholesalers to plain region (about 100 km away from production area) where the produce was auctioned by the wholesaler separately for each farmer in the wholesale market. After auction, the lot was mixed and a part of it was transported back to the hilly regions of Uttarakhand for retail and food services supplies. Therefore, grading facility in the production area and local market yard was recommended to improve the infrastructure.
- **In Punjab, tomato** was grown for fresh consumption (slightly lower TSS) and PHL was very high due to glut in the market in the production season. Therefore, diversion of produce to distant market was suggested.
- **Early cauliflower** (October-December) fetched high prices and even inferior quality was sold and practically no loss was observed. However, in the production season, the prices were very low and only very high-quality cauliflower could reach for retail. Technology for drying of cauliflower and other vegetables was recommended in such catchments.
- In Andhra Pradesh, Odisha, West Bengal and Bihar, **paddy harvesting coincided with the monsoon rain,** which caused higher losses during drying. Therefore, development of on-farm dryer was the recommendation of the study.

6. IMPACT OF POST-HARVEST FOOD LOSSES AND FOOD WASTES

Studies on the social, economic, and environment impacts of FLW are negligible. The FLW not only reduce the quantity available for human consumption, but also pressurize the natural resources. Each PHL report has used different approach and reporting details, such as losses of calories, nutrients (vitamins), greenhouse gases (GHG) or carbon footprint. An example of an early attempt at calculating FLW effects on natural resources can be found in Kummu et al. (2012). In general, according to FAO (2011) and Kummu et al. (2012) the production of fruits and field-grown vegetables generates relatively low GHG emissions. For agricultural production, emissions are mainly due to the use of diesel and nitrogen fertilizers, as well as yield level. Potatoes and other roots and tuber crops are particularly efficient in the cultivation because of very high yield per unit area, so emissions of GHG per kg of roots and tubers crops are low. The impact of FLW is defined in **Table 8** (WWF-UK, 2021).

Table 8: Definition of Impact of Food Loss and Waste

Impact	Definitions
GHG Emissions	GHG emissions resulting from farm-stage activities include those associated with harvest, on-farm handling, processing and storage, but before transportation off farm for any further processing, storage and distribution. The calculated carbon footprint comprises of emissions to air from carbon dioxide, methane and nitrous oxide, expressed as CO_2 equivalent (CO_2 eq.).
Water Use	Water used to grow crops and maintain livestock. Water withdrawals include irrigation withdrawals, irrigation withdrawals embedded in feed, drinking water for livestock, water abstracted for aquaculture ponds as well as processing water.
Eutrophication	Eutrophication is the process whereby aquatic systems become over-enriched by nutrients, such as nitrogen and phosphorus, released through run-off from agricultural activities (such as fertilizer application) into lakes and rivers. This alters the aquatic environment, placing local biodiversity at risk.
Acidification	Acidification is the process in which the pH of soil or water environment becomes more acidic. The main sources for high acidification potential can be linked back to farming activities and to the production of key inputs, such as fertilizers and pesticides. This can reduce the soils fertility, eventually meaning the land can no longer be used to grow crops, and adversely impact aquatic ecosystems.
Land Use	The land use associated with food waste is the total land area that would be needed to produce an amount of food equivalent to that wasted.
Biodiversity Loss	Biodiversity refers to the genetic variability, number and variety of species in an area; it is essential to planetary functioning and even small losses can have catastrophic effects on ecosystem structure and functioning. The impact of farm-stage food waste on biodiversity is assessed based on factors that may affect or present risks to biodiversity, such as land-use change and water use.

Source: WWF-UK, 2021

6.1 Social Impact

Any increase in FLW leads to food and nutrition insecurity, especially in situations when supplies are already constrained or households do not have the means to access a secure food supply. Often, it is women and individuals in marginalized communities who bear the consequences. When there is limited food, it is traditionally the female members of the household who forgo their meals, leading to nutritional deficiencies (Salcedo La-Viña et al. 2020).

Post-harvest operations such as winnowing, drying, and storage are the predominant responsibility of women, particularly in low-income countries, and therefore it is important to assess the existing knowledge and level of adoption of post-harvest technology by women (Hegazy 2016). Yet, gender aspects are mentioned in few studies only.

PHLs are generally higher for marginal and small farmers than for farmers with large land holdings, as the latter have better access to facilities and equipment (Kannan 2014; Grover and Singh, 2014). Most of the farmers in the low-medium income countries have limited landholdings and mostly work as farm labourers. Those who do own land have limited resources, which leads to more losses.

High income countries possess supply-chains, which are integrated and mechanized with differing capabilities. These countries have a relatively high affordability for food (as a proportion of total income) and still experience food insecurity. For example, even today in the USA, 40% of food goes to waste at an economic cost of US$165 billion annually, whilst one in six citizens lack food security. Within the EU, nearly 90 MT of food waste was generated in 2006 while 5.6 million people in UK alone live in deep poverty (Bond et al., 2013).

6.2 Economic Impact

The total annual economic, environmental and social costs of FW to the global economy are in the order of US$ 2.6 trillion (FAO, 2014), and the figures attributed to each of these aspects are shown in the **Table 9.**

Each PHL and FW study has used different approaches for measuring, calculating and reporting on economics of losses. Most of the PHL studies that reported on economic losses in Africa and Asia were conducted by researchers working with Asian Vegetable Research and Development Centre (AVRDC) or World Food Logistics Organization (WFLO).

The **ICAR-CIPHET** study estimated the implications of food loss for the country's economy (Jha et al., 2015). It estimated that the economic value of the quantitative loss of 45 crops and livestock produce is INR 926.51 billion (US$ 15.19 billion) at average annual prices in 2014, which is 2.5 times higher than the budgetary allocations to the Ministry of Agriculture and Famers Welfare, Govt. of India. This economic losses do not even include the value of FW, which was approximately 0.6% of India's GDP in FY2014 (Agarwal, 2021).

Kitinoja (2010) reported the economic losses at the retail level for amaranth (30%) and pineapple (33%) in Benin due to mechanical damage and weight losses. The 100% damage of cooking bananas in Rwanda resulted in a 20% loss in market value at the retail level (Kitinoja et al., 2018).

Table 9: Global Costs of Food Waste

Aspect	Cost (US$)
Economic	1 trillion
Environmental	700 billion
Social	900 billion
Total	2.6 trillion

Source: Food Waste Footprint FAO, 2014

FAO (2015) study in the Caribbean calculated economic losses in cassava as they were measured as "unfit for sale" in Trinidad and Tobago as US$ 500,000 and in Guyana as US$ 839,000. One study reported the economic losses for tomatoes and cauliflower per trader, wholesaler and retailer (Kitinoja et al., 2018). Gautam and Buntong (2015) reported the economic losses per hectare for vegetable crops in Cambodia and found approximately US$ 4,213 per ha for tomato and US$ 2,208 per ha for leafy mustard.

WFLO's PHL studies for Committee for Economic and Commercial Cooperation (COMCEC) reported on the range of annual farm level economic losses in Uganda (bananas, plantains, maize), Nigeria (cassava, sweet potatoes) and in Egypt (tomatoes) - (Kitinoja et al., 2016). The economic losses for Uganda's maize farmers is in the range of US$ 70-126 million per year. For Egypt, the economic losses for tomato farmers were approximately US$ 255-340 million per year (Kitinoja et al., 2016).

6.3 Resources Loss

The amount of crop land used to grow the lost and wasted food is 1.4 billion hectares per year. Furthermore, 28 MT of fertilizer (23% of total global fertiliser use) are used annually to grow the lost and wasted food (Lipinski et al. 2013, FAO 2019). Waste of fertiliser is an important issue because of the following factors:

(a) Fertilizers contain nitrogen that is converted into nitrous oxide, which is the third most potent GHG following carbon dioxide and methane, depleting stratospheric ozone.

(b) They consume finite natural resources (e.g., phosphorous).

(c) Fertilizers can have a negative impact on water quality (Kummu et al. 2012).

The usage rate of nitrogen fertilizer is the best single predictor of nitrous oxide emissions from agricultural soils, which are responsible for about 50% of the total global anthropogenic flux. Accumulating evidence suggests that the emission response to increased application of nitrogen fertilizer is exponential rather than linear. **Researches show that 1.75-5 kg of GHG emissions are produced for every 100 kg of fertilizer application in soils (Shcherbak et al. 2014).**

FLW is associated with approximately 173 billion m^3 of water consumption per year, which is 24% of all water used for agricultural production (FAO, 2019). Average water footprint values for cultivating one kg of rice, cotton, sugarcane, roasted coffee, chicken, milk, and egg require 3000-5000, 22500, 1500-3000, 18900, 4300, 1020, and 3300 litres (Naveena et al. 2020). This highlights the criticality of FLW in terms of water footprint. Based on ICAR-CIPHET study, the water loss was estimated (Kashyap and Agarwal 2019; Ravi and Umesh 2018). **The study revealed that losses in rice and sugarcane resulted in the largest water loss.** The water footprint of the total FLs was 115±4.15 billion m^3 (105±3.77 billion m^3 of direct water use and 9.54±0.38 billion m^3 of indirect water use). However, the estimated water loss by Kashyap and Agarwal (2019) and Ravi and Umesh (2018) seems to be unrealistic when it is compared with FAO (2019) report. PHL for tomatoes and green chillies in Rwanda were translated into water use of 7,073 m^3 per ton and 170 m^3 per ton, respectively. The blue water footprints (water use during life cycle of food) for the global FW was estimated to be about 250 km^3 (FAO, 2013, Fox, 2013).

Rice accounted for the total land footprint of FL by 9.58±0.4 million hectares. A study conducted on rice PHLs in Nigeria estimated that the lost paddy accounted for 19% of the total cultivated area (GIZ, 2014). **On the global scale, about 1.4 billion hectares of land was wasted by growing food that was not consumed in the year 2007, an area larger than Canada and China (FAO, 2013).**

However, the method of resource loss estimation is not uniform and many reports show exaggerated values of resource loss.

6.4 Environmental Impacts

FAO observed from the life cycle perspective that about 3.3 G tonnes of CO_2 equivalent emissions arises every year due to food that was produced but not consumed, without even considering the land use change (FAO, 2013).GHG emissions derived from total UK energy consumption is approaching 1 billion tonnes CO_2 emission annually (World Bank Group, 2020). Rice accounted for the total carbon footprint of 64.1 MT CO_2 eq. in India (Kashyap and Agarwal 2019), which is unrealistic. FLW for tomatoes and green chillies in Rwanda resulted in estimated GHG emissions of 161 kg CO_2 eq. per ton (24 million kg CO_2 eq.) and 12 kg CO_2 eq. per ton (53,000 kg CO_2 eq.), respectively.

Besides these, one major impact of the FLW is the loss of biodiversity. High biodiversity impacts come from additional rearing of livestock, particularly land-use change, invasion of wild animals and degradation of their habitat due to overgrazing, additional environmental pollution (livestock as well as manure management), deforestation for field crops, etc.

6.5 Impact of FLW Reduction

FAO has targeted in SDG-12.3 to reduce FLW by 50% by 2030, which includes 50% FW reduction at the retail and consumer levels and reduce FLs along production and supply chains, including PHLs (FAO, 2021b). Such reduction by 2030 may have major impact on food availability and resource use. Based on the FAO (2019), FLW data, production and resource use estimates in 2019 (FAO, 2021b), it is estimated that the average global FL was 25.4% and FW was 9.7% in 2019. An estimate of reduction in FLW by 50% till 2030 and estimated saving of some of the resources is given in **Table 10**.

However, reduction in PHL by 50% is quite difficult because PHL in some of the unit operations are unavoidable. The focus should be on reducing FW, which may help in reducing resources loss and combat with the hunger in the world.

Table 10: Resources Saving due to the Reduction in PHL (60% of 25.4%) and FW (50% of 9.7%) by 2030

Aspect	Resources in 2019 at Global Level	Saving due to PHL Reduction by 50% by 2030 (MT)	Saving due to FW Reduction by 50% in 2030 (MT)
Production of primary Crops (Million Tonnes)	9356.51	1188.28	453.79
Crop Land (Million Ha)	1556.06	197.62	75.47
Pesticide Use (Thousand Tonnes)	4190.99	532.26	203.26
Inorganic Fertilizer Use (Million Tonnes)	188.53	23.94	9.14

Source: Compiled by Authors

7. RECENT TECHNOLOGICAL INTERVENTIONS IN REDUCING POST-HARVEST LOSS IN THE WORLD

Mechanization of post-harvest operations has been found to have positive impact in reducing the losses. Mechanization aids in timely harvesting and completion of other farm operations with improved efficiency, improves quality of produce, value addition and reduces microbial load with long shelf life (Vishwakarma et al., 2020). Useful technologies to reduce FLW are discussed in this section.

7.1 Interventions to Reduce Storage Losses in Food Grains

Although it is challenging, storage losses can be mitigated by use of efficient storage technology, upgrading infrastructure and storage practices. Some of the improved storage structures and practices to reduce PHL in food grains are discussed below:

7.1.1 Cover and Plinth Storage

The need arises at several occasions, particularly at the harvest period, for temporary storages of food grains for short term by the procurement agencies due to lack of covered storage space, particularly in developing countries. Stacking of bags is done on a wooden frame (dunnage) placed on a raised platform (plinth), and the lot is covered with 800-1000 gauge thick polyethylene sheets. This storage method is known as cover and plinth (CAP) and common for the storage of wheat and paddy for less than six months to one year at present in India. Dunnage is the structure made from wooden planks in general on which the bags are stacked. Polyethylene sheet alone or sandwiched between two layers of mats, bamboo are also suitable for use as dunnage for short-term storage. A wooden dunnage is made using timer planks in which the planks are one over the other and nailed. The lower member of dunnage is of 100×50 mm^2 rectangular shape and 1 m long. In general, five planks at 362 mm distance from centre to centre are used. The upper member of dunnage is of 70×50 mm^2 cross-section, 1.5 m long and 5 planks are placed at 237 mm distance from centre to centre.

7.1.2 Warehouses

Warehouses are used for the storage of bagged grains to safeguard them from environmental factors. Covered storage warehouse is a very common grain storage method in many developing countries. Any type of shaded structure or building, such as stone structure, brick wall, corrugated sheet walls, mud and wattle walls with or without plaster, earthen walls, floor of stone, slab, or thatched roof can be used for stacking of bagged grains. Storage losses in wheat and rice are bare minimum (<0.5%) for 3 years storage in warehouses when proper storage management protocols are adopted (Kumar et al., 2022).

7.1.3 Silos

A metal silo is a strong hermetically sealed structure (mostly cylindrical), built using a galvanized steel sheet, and has been found to be very effective for storing grains for long periods of time and avoiding insects and rodents. In some locations, the silos are made of painted aluminium sheeting which help in preventing corrosion and improving their appearance. It is considered to be one of the key technologies which will be helpful in reducing postharvest losses and improving food security of smallholder farmers. While there are a number of types of silo structures, they essentially have feeding from the top, whereass the grain is removed from the bottom hopper with the help of mechanised elevator systems. Silo storages provide an easy advantage of fumigation and aeration and removes the necessity of using bags. However, these are economically valid for storing large quantities (over 25 tonnes) and are often regarded as too costly for small scale storage. Their initial high cost is also a major obstacle for their adoption by smallholders. Community level silos might be an economic alternative, as the cost per unit of grains decreases with increases in the size of silos. The maintenance cost is very low in the case of silos, which can compensate for the high initial cost to some extent.

7.1.4 Hermetic Enclosures

Grain storage in a flexible hermetic plastic storage structure/enclosure, which serves as gas and air barrier when assembled and closed, is used for storage of dry sensitive and non-sensitive food grains. Such enclosures are available in 5 to 300 tonnes capacities. These are made of reinforced poly vinyl chloride material. Some enclosures are made of single layer using high density polypropylene thermo-elastic material, which naturally inhibits the permeability of both air and microorganism and maintain an air tight environment. However, capacity remains one of the greatest impediments of such storage. This makes it a space demanding type of storage. Material used for the manufacturing of enclosure is also not very durable, and largely non bio-degradable.

7.1.5 Hermetic Storage

Hermetic storage (HS), also known as "sealed storage" or "airtight storage", is gaining popularity as a storage method for cereal, pulses, coffee, and cocoa beans in developing countries due to its effectiveness and avoiding use of chemicals and pesticides. The method creates modified atmosphere of high CO_2 concentration using sealed waterproof bags or structures. Hermetic storage has been observed to be very effective in avoiding the losses (storage losses less than 1%) during long distance (international) shipments also (Villers et al., 2010). Ease of installation, elimination of pesticide use, favourable costs, and modest infrastructure requirements are some of the additional advantages that make the hermetic storage options attractive.

Purdue Improved Crop Storage bags (PICS), originally developed for storage of cowpea, involve triple bagging the grains in hermetic conditions, and is widely used by farmers in sub-Saharan Africa. The grains are stored in double layer thick (80 µm) high density polyethylene (HDPE) bags and are held in a third woven nylon bag. After filling with the grains, the bags are sealed airtight. This cuts off the oxygen to the weevils and hinders their metabolic pathways preventing them from producing water, and killing them by desiccation (Murdock et al., 2012). These bags are made of a single thick layer of high-density polypropylene with a thickness of about 78µm, and used as liner along with normal woven polypropylene bags. Some of the bags available in the market are insecticide infused woven polypropylene bags designed to prevent damaging due to pest infestations. The bag is made with parathyroid incorporated into polypropylene yarns.

7.1.6 Chemical Fumigation

Synthetic insecticides are used worldwide to control insects and pests to reduce food grains storage losses. Methyl bromide (MB) and phosphine are the most used chemicals worldwide; however, methyl bromide was banned for use as a fumigant in several countries in 2002 because of toxicity and contribution towards the depletion of ozone layer. Due to long use of phosphine, some insects have gained resistance to chemical fumigation in some countries (Villers et al., 2010). Use of these chemical fumigation methods is even challenging in the traditional storage structures used in the developing countries, as most of them are open to re-infestation. Another challenge with these chemicals is knowledge and training to apply these pesticides at the correct time and at the correct dose. The delayed treatment, adulterated chemicals, and incorrect dosage can reduce the efficacy of the treatment and result in high storage losses.

7.1.7 Alternates to Phosphine Fumigation

7.1.7.1 Inert Dust: Inert dusts such as clay, sand, rock phosphate, ashes, diatomaceous earth, and synthetic silica have been used as insecticides for thousands of years by aboriginal peoples and are also used in modern grain storage facilities (Fields and Korunic, 2002). Humidity, grain porosity, sharpness of the inert dust are the factors affecting its efficiency. When humidity inside the storage silo is high, it causes less desiccation to the insects. As porosity of the grain increases, the insect movement is also increased and leads to quick desiccation. Increase in the sharpness of inert dust increases the damage of cuticle. Inert dusts are applied as dusting on the grain surface or the top 10-20% of the grain. It is also applied by blowing inert dust into the storage silo by aeration.

7.1.7.2 Storage of Pulses between Sand Layers: Taking into consideration the insects' behaviour to seek the top surface in a storage bin for mating and egg laying even though they emerge from the grain far below, the technique of sand layer of 30 mm over the grain surface is used to prevent bruchid infestation in pulses. Germination of black gram, green gram and pigeon pea seed can be retained even after nine months of storage under sand layer in the modified bins compared to the seed stored conventionally in gunny bags (Swamy et al., 2018). However, practical difficulties in bulk storage limits its applications.

7.1.7.3 Controlled Atmosphere: Controlled atmosphere (CA) fumigation is altering the composition of air inside a storage structure. Controlled atmosphere kills the insects by suffocation when low oxygen environment is created. CA storage has been shown to be promising in creating lethal conditions for insects and fungi in stored food commodities and capable of eliminating all stages of insects and pests. Air tightness, temperature, grain moisture are the important factors affecting the controlled atmosphere fumigation. The method of application involves passing CO_2 to the storage setup to create the CO_2 rich atmosphere. However, construction of airtight storage structures, such as silos and warehouses is still a technical challenge for food grain storage.

7.1.7.4 Carbon Dioxide Fumigation: CO_2 is colourless, odourless and non-flammable gas and kills the insects by suffocation. More than 37.5% concentration of CO_2 in air is toxic to most of the insects. The efficiency of the CO_2 fumigation depends on concentration, airtight condition of storage structure, grain moisture content, species and life stage of insects, temperature and time. CO_2 fumigation is done by passing the gas to the stack of grain bags covered by HDPE without any leakage **(Figure 5)**. CO_2 gas pass from the top as it has higher density than air. For silo storage, CO_2 gas is passed from the liquid CO_2 tank, which is vaporized using vaporizer. The CO_2 air is passed through the diffuser nozzle at bottom of the silo by pump. However, maintaining proper CO_2 levels in grain storage structures and fabrication of large capacity air-tight silos is still a challenge as a particular concentration has to be maintained for disinfestation.

7.1.7.5 Microwave and Infrared Heat Treatment: Microwave and Infrared treatments are non-chemical alternative for insect control in stored grains through dielectric heating, which is based on the food grains electrical properties. Selective heating of insects is possible rather than grains due to their poor electrical conductivity. The fumigation is performed in a batch type or continuous microwave system. A pilot-scale microwave system is shown in the **Figure 6.** Grains are kept inside the microwave system and the grains are

Figure 5: Schematic Diagram of CO_2 Disinfestation Silo Setup

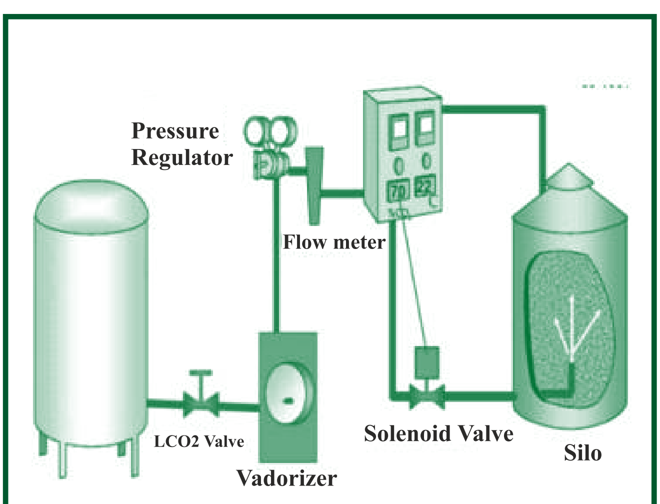
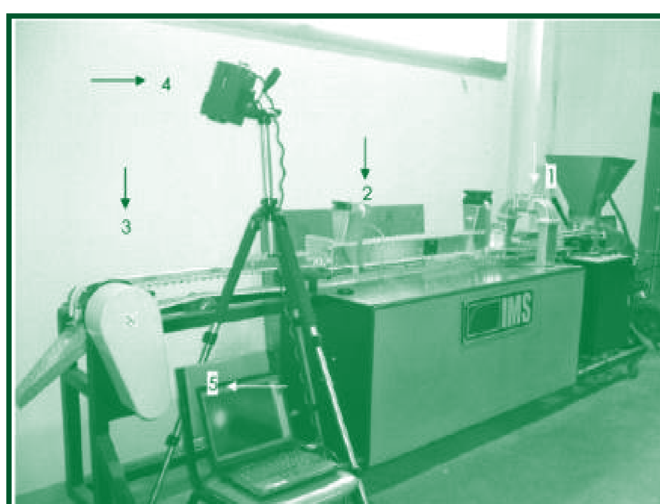


Figure 6: A Continuous Microwave Fumigation System



Source: Vadivambal et al., 2010

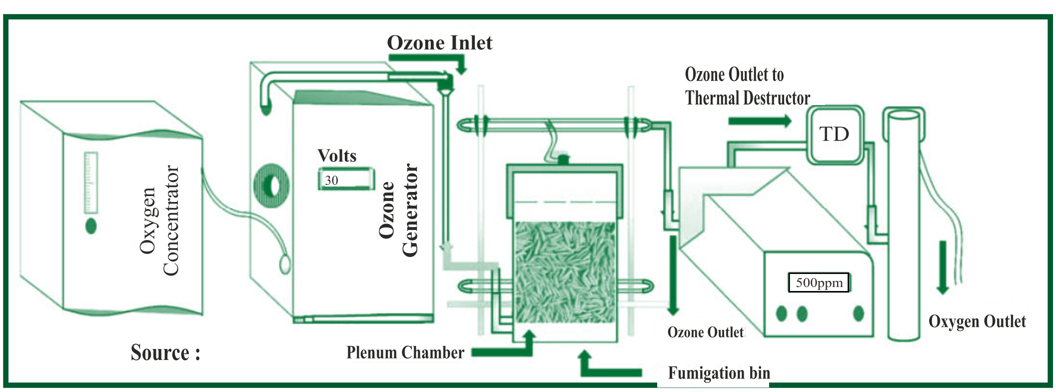
exposed to different microwave power level and duration. Due to limited penetration depth of microwave, the grains are kept in thin layers. One of the major issue with microwave heating is the non-uniform temperature distribution in a grain mass, which may cause ineffective control of insects.

7.1.7.6 Fumigation using Ozone: Ozone is an ionized, unstable, colourless gas with pungent odour. Oxidation potential of ozone is high (~2.07 V) due to the electron arrangement of the molecule. High oxidation property is lethal to the major stored-grain insects viz., S. *oryzae, O. surinamensis, Tribolium* spp., and *E. elutella* and various fruit flies and this treatment has been used as a fumigation agent in stored grains. Fumigation system **(Figure 7)** consists of an oxygen concentrator, ozone generator, pilot scale storage bin, ozone analyser and ozone destructor (Pandiselvam et al., 2017). Grains are exposed to ozone gas for specified time period. After fumigation ozone is flushed into atmosphere. This technology is not adopted for commercial purposes at present.

7.1.7.7 Cold Plasma: Plasma is a quasi-neutral ionized gas and it is in fourth state of matter i.e. conversion of gas into plasma as increase in enthalpy of gas. During plasma generation, free electrons of the plasma collide with each other and give excitation of energy to create unique, highly reactive products and emit UV light. The components of plasma gas kill the insects by suffocation, oxidation, and desiccation, DNA strand breaking and heating. Ionizing ultraviolet light with the wavelength of 10-400 nm and photon energy 3-124 eV is used for surface treatment of grain and to control stored product insect pests. The mortality of insects by cold plasma depends on the flux of the plasma, time and moisture content. Use of cold plasma is not done for bulk storage at present. A schematic diagram of cold plasma fumigation system is given in the **Figure 8 (Page 39).**

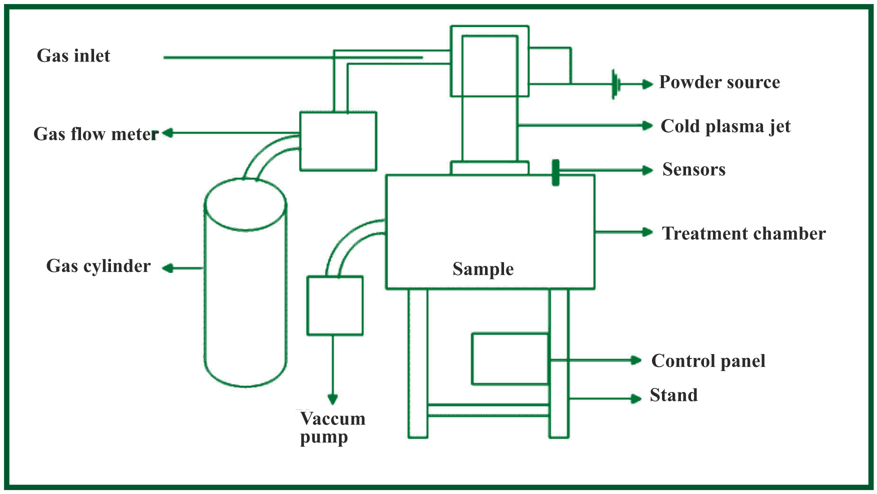
7.1.7.8 Plant based Insecticides: Several plant species and their extracts act as natural pesticide and are used commonly in traditional practices to protect the grains from insects in several African and Asian countries. Plant based chemicals and products are biodegradable, environment friendly, and relatively safe for human health. The leaves and oil extract from *Chenopodium ambrosioides* Linn. (Chenopodiaceae), for example, has been found to be effective in controlling the insects of cereals during storage. The major issue with plant extracts is that oil yields are low and might be expensive to use for commercial purposes, however, some plant leaves can be used as natural insecticides by small holders.

Figure 7: Schematic Diagram of Ozone Fumigation Setup



Source: Pandiselvam et al. 2017

Figure 8: Schematic Diagram of Cold Plasma Disinfestation Setup



Source: Compiled by Authors

7.2 Technologies for Fruits and Vegetables

F&V are metabolically active, undergo ripening and senescence changes, which has to be controlled to preserve quality and prolong shelf life (Mahajan et al., 2014). The choice of technology depends on crop type, climatic conditions, affordability and ease of use. Postharvest technologies intend to retard ripening and senescence changes, thereby minimise crop spoilage and microbial growth. Environmental management is again a key factor in reducing losses during storage of F&V.

7.2.1 Temperature Management

Temperature is an important factor that influences the storage life of perishable commodities. Pre-cooling is an important and first step for fresh produce pre-treatment. Effective temperature management depends on removal of field heat as soon as possible after harvest, which can be done by several methods such as, hydro cooling, ice toping, evaporative cooling, forced air cooling and vacuum cooling that precede further processing.

On the other hand, low temperatures can result into chilling injury and loss of cellular structure caused by collapsing of F&V tissues. Chilling injury affects mainly tropical and subtropical F&V due to their sensitivity to temperatures below 12°C. Some of the deleterious effects associated with low temperatures are failure to ripen, pitting, surface and internal discoloration, off flavours and microbial growth. However, high temperatures are implicated with heat injury and consequences on water soluble micronutrient losses such as, vitamin C and B. High temperatures due to sunlight can cause localized bleaching, sunburn and sunscald.

7.2.1.1 Heat Treatment: Heat treatment include blanching, hot water dip, saturated water vapour, hot dry air, and hot water rinse with brushing. Heat treatments can be of short duration (up to 1 h) or long duration (up to 4 days) at 37-55°C or in hot water of 63°C for <1 minute (Mahajan et al., 2014). Heat treatment preserves colour of F&V, prevent development of off flavours, harden tomatoes, carrots and strawberries, and increase shelf life of plums, peaches, carrots and grapes (Mahajan et al., 2014). For example, mango treated at 50°C retain overall fruit's eating quality and weight as compared to untreated after five days of storage in a study conducted in South Africa (Sivakumar et al., 2012).

7.2.1.2 Low Temperature Treatment (Refrigeration and Freezing): Low temperatures treatment is one of the effective methods to preserve quality and extend postharvest life of F&V and maintain quality attributes like texture, colour, nutrients, aroma and flavour for long duration storage. Refrigeration temperatures ranges from 1-4°C, while freezing temperatures ranges from -18 to -35°C. For tropical F&V of the Sub-Saharan Africa, low temperature conditioning is recommended before storing under refrigeration or freezing temperatures to prevent chilling injury. It is also recommended to manage F&V temperatures and maintain the cold chain throughout the distribution and market operations to retain freshness and nutritional value.

7.2.2 Delay Ripening and Curing

Physical treatment, irradiation, edible coating, chemical treatment, nitric oxide, sulphur dioxide treatment, ozone, 1-Methylcyclopropene, Amenoethoxyvinyl gycine, silver nitrate, silver thio-sulfate, benzothiadiazole, controlled atmosphere packaging, modified atmosphere packaging, are some of technologies which inhibit ethylene production and action during ripening and storage of F&V, thereby extending shelf life (Mahajan et al., 2014)

7.2.2.1 Calcium Application: Calcium Chloride ($CaCl_2$) at low temperatures is used to suppress senescence, reduce chilling injury, control development of physiological disorders and increase disease resistance in stored F&V. This chemical prevents chilling injury in stored African eggplant (Chepngeno et al., 2015). Tomatoes treated with $CaCl_2$ were stored for 21 days without spoilage and indicated little change in physiochemical properties in Nigeria (Anyasi et al., 2016).

7.2.2.2 Edible Coating: Edible coating is a thin layer of edible materials applied on the surface of fresh F&V to protect them against spoilage microorganisms and physical damage. Also, edible coating minimizes moisture loss, slows down respiration, senescence and enzyme activity, preserves colour, flavour and texture, thereby, retains freshness, active volatile compounds and plant antioxidants (Mahajan et al., 2014). These coatings are: applied directly on F&V surface by spraying, dipping, smearing or brushing followed by drying to create a modified barrier. Their functions and effects depend on the type of coating materials, temperatures, alkalinity, thickness, as well as, variety of F&V. Approved F&V edible coatings are chitosan, cellulose, starch, gum (polysaccharides), bees and paraffin wax, mineral oils, polyvinyl acetate and several proteins based coatings (like gelatin and soy proteins). These are mainly used in combination with antioxidants, antimicrobials, or nutraceutical and functional compounds. Edible coating provides a carrier for postharvest chemical treatment on F&V and reduces the use of synthetic packaging materials, thereby reducing the risks of GHG (Alam et al., 2014). Tomato surface coating with Gum Arabic has improved shelf life, delayed weight loss, maintained firmness and colour (Ali et al., 2013). Cucumbers and avocados coated with edible chitosan retained firmness and their quality for 14 days in Nigeria and South Africa (Omoba & Onyekwere, 2016).

7.2.2.3 Sanitizing Chemicals: Several chemicals are used to sanitize surfaces and processing areas for F&V to reduce, remove or kill spoilage and pathogenic microorganisms (Ramos et al., 2013). Most of cleaning and sanitizing chemicals are chlorine (hypochlorite, chlorine dioxide), ozone, hydrogen peroxide, trisodium phosphate, organic acids (acetic, lactic, citric and tartaric acid), electrolyzed water and calcium based solutions. Depending on a crop and situation, sanitizing chemicals are applied at different recommended concentrations by dipping, rinsing or spraying on F&V surfaces for a predetermined contact time. Tomatoes treated with chlorine water showed a significant reduction in coliform and fungal counts on surfaces in a study conducted in South Africa (Sibomana et al., 2017).

7.2.2.4 Curing: The term "curing" is applied to the measures used to prepare starchy staple root crops and onions for long-term storage. The method of curing root crops is different from the method that is used for onions. The curing of root and tuber crops replaces and strengthens the damaged areas of corky skin, restoring protection against water loss and infection by decay organisms.

Curing must be carried out as soon as possible. This can be done by limiting ventilation, thus allowing the temperature to rise enough to promote curing. At the same time the air will become moist owing to the normal production of water by the roots and high rate of evaporation from injuries. Cassava discolours and decays at very fast rate. Curing of the dry bulb onions is carried out immediately after harvest in which harvested onions are left in the field for a few days until the green tops, outer skins and roots are fully dried. Under wet conditions, it may be necessary to dry onions on racks or trays under cover.

7.3 Preservation and Minimal Processing

Food processing refers to the application of specialized techniques to prepare/develop foods in a systematic manner through preservation for extended period, packaging, storage and distribution, ultimately to ensure greater availability of a wide variety of foods, which might facilitate to enhance the food intake and nutritional standards during the periods of low availability. The aims of food processing are extending shelf-life, providing (supplement) nutrients required for health, providing variety and convenience in diet, and adding value (Fellows, 2009).

7.3.1 Preservation

Food preservation is the method of enhancing the storage life by creating hurdles for the growth of spoilage microorganisms. Different food preservation techniques are practised since time immemorial. These techniques can be separated into two groups: physical and chemical methods.

7.3.1.1 Physical Methods: Preservation under this category helps in stopping the growth or kills the microorganisms present in the food. It includes canning and freezing along with other methods such as drying, irradiation, ultraviolet or high intensity white light, ultra high pressure, filtration and packaging and containerization.

7.3.1.2 Chemical Methods: Chemical preservatives work either as direct microbial destroyer or by reducing the pH that prevents the growth of microorganisms. Food Laws have classified preservatives into two classes as Class-I (natural preservatives) and Class-II (synthetic preservatives).

7.3.2 Freezing of Foods

It is a method of preserving processed food by lowering the temperature to inhibit microorganism growth. Freezing is one of the most efficient methods to retain the essential nutrients. The superior quality of frozen foods is made possible by the development of individually quick-frozen (IQF) method. IQF is a technique that inhibits large ice crystals formation in cells. Frozen F&V have preeminent quality and nutritive value.

Various freezing techniques are widely adopted in the preservation of F&V products. These techniques include blast freezing, plate freezing, belt-tunnel freezing, fluidized-bed freezing, cryogenic freezing, and dehydro-freezing. The choice of method depends on the quality of end product desired, types of F&V, capital limitations, and bulk or individual retail packaging requirement. Various types of frozen tropical F&V include cantaloupe, figs, fig puree, fruit bar, honey dew, mango, mango puree, melon, pineapple, pineapple puree, leafy greens, mushrooms, okra, peppers, summer squash, sweet potatoes, mushroom and pecan puree, pepper puree (APEDA, 2007). Fruits kept at -18°C can usually retain good quality for 12 months and vegetables for 8-12 months. Increasing storage temperature results in shorter shelf life. For each 10°C increase in temperature, the storage time is approximately reduced to half.

7.3.3 Minimal Processing

Minimally processed F&V are prepared using non-thermal treatments to maintain freshness, remove non-edible parts in the production catchments while keeping safety and quality right. The process involves cleaning, trimming, slicing, shredding, dicing, sanitizing, packaging, freezing, and some other operations depending on type and consumer demands. Fresh-cut F&V processing induces injury in tissues, thereby accelerating microbial growth and spoilage as the consequence and hence have less perishability and more susceptibility to pathogenic and spoilage microorganisms. Therefore, minimal processing need high level of sanitation, process hygiene, quick transportation facility with market linkage and knowledge of food technology and postharvest physiology. Minimally processed F&V requires refrigeration throughout the supply chain. Furthermore, MAP, active and smart packaging, Moderate Vacuum Packaging (MVP), and Equilibrium Modified Atmosphere Packaging (EMAP), are used to maintain quality and shelf life of minimally processed F&V. Shelf life of minimally processed F&V has an average of 7 days.

7.3.4 Blanching

Blanching is a thermal method used extensively for vegetables before freezing, drying or canning. It helps in product decontamination, microbial load reduction, entrapped gases removal and wilting the tissues and allows easy and convenient filling in the containers. However, its primary purpose is to inhibit enzymes that are responsible for deterioration, off-flavours, and aromas during frozen storage. The F&V are sorted, washed and cleaned for blanching in hot water at 88°C for 2-5 min or with steam in a conveyor at 100°C for 30-60 sec.

7.3.5 Dehydration

Dehydration is one of the oldest techniques of preserving foods. Dehydration refers to the nearly complete removal of water from the perishables under controlled conditions with minimum changes in food properties. Removal of water results in huge volume and weight reduction that makes storage and transportation easier. The simplest method for dehydration is sun drying but the products obtained are of inferior quality. Modern drying techniques are complicated or sophisticated. Nowadays many dryers are available, which can achieve high end processes such as tunnel drying, vacuum drying, drum drying, spray drying, and freeze-drying.

7.3.6 Osmotic Dehydration

High concentration sugar or salt solutions are used to soak the fresh material in osmotic dehydration and then the material is dried. Due to the difference in the concentration of solutes, water flows from the F&V to the surrounding medium and thus it loses moisture. The syrup or salt gives protective effect on colour, flavour and texture during osmotic treatment.

7.3.7 Processing before Maturity

Some fruits like mango and banana are useful when harvested at a full grown, but unripe stage. These fruits are processed into value added products like pickles, cuisine dishes and others. Harvesting at an unripe stage gives extra time to the producers to streamline products for different processing applications. Similar practices is advocated so that a segment of produce can be diverted for value addition when there is an expected glut in the market during the peak harvest season.

7.4 Proper Storage

Proper storage facilities are crucial in reducing FLW. This can include the use of cold storage facilities to protect the crops from environmental factors. Some of the low-cost as well as advanced and effective storage strategies to reduce FLW in F&V are discussed below:

7.4.1 Evaporative Cool Chambers

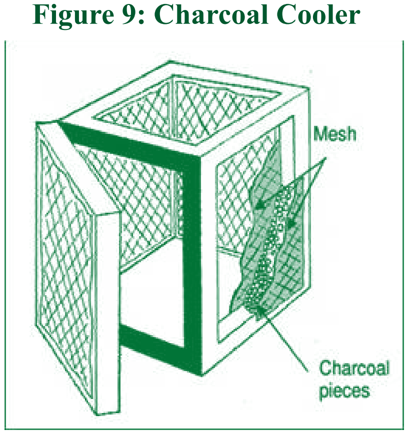
Evaporation cooling is used to cool the produce with the help of a physical phenomenon in which evaporation of a liquid into the atmosphere, typically into surrounding air, results in cooling of an object or a liquid in contact with it (Ndukwu and Manuwa, 2014). Humidity of the surrounding air controls the rate of evaporative cooling, hence, determining its efficiency. A perforated floor accommodates the air conducts and air is forced into the produce. To ensure a uniform distribution of air through the stored produce, fans are installed. Some of the evaporative cooling structures are explained below:

7.4.1.1 Pot Design: This is the simplest design of evaporative cooler and can be used at home. A bigger pot that holds water has a storage pot placed inside. The food to be cooled is kept in the inner pot. One adaptation of this design is the *Janata* cooler (**Figuress 9 and 10),** which has been developed by the Food and Nutrition Board of India. A storage pot is kept in an earthen bowl containing water. The pot is thereafter covered with a wet cloth that is dipped into the reservoir of water. Water is drawn up by the cloth from the bowl that evaporates and thus keeps the storage pot cool. The bowl is isolated from the pot by wet sand from the ground.

7.4.1.2 Charcoal Cooler: The charcoal cooler is made from an open timber frame of approximately 50mm × 25mm in section. The door is designed as simply hanging from one side of the frame (Figure 9). The wooden frame is wrapped in mesh, inside and out, leaving a 25 mm cavity which is filled with charcoal pieces. To achieve evaporative cooling, the charcoal is sprayed with water. . The framework is mounted outside the house on a pole with a metal cone to keep rats and other rodents away and a good coating of grease is used to prevent ants from getting to the food. The top is usually solid and thatched, with an overhang to inhibit flying insects (Kale et al., 2016).

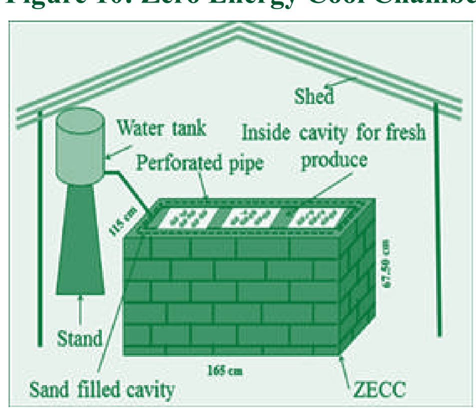
7.4.1.3 Evaporative Cool Chamber (ECC) or Zero Energy Cool Chamber (ZECC): These chambers have been designed based on the

Figure 9: Charcoal Cooler



Source: Odesola and Onyebuchi, 2009

Figure 10: Zero Energy Cool Chamber



Source: Khalid et al., 2020

principles of direct evaporative cooling. The storage mechanism does not require any electricity or power to operate and the materials required for the construction, like bricks, sand and bamboo are locally available (Figure 10). It is a double brick-wall structure. The chamber walls are soaked in water and cavity is filled with sand. The chamber can be constructed by unskilled labour as it does not require any specialized skill. The temperature can be reduced by 10°-15°C and high humidity of about 90% can be maintained in ZECC that can increase shelf life and retain quality of fresh produce. Such practices can avoid middle men in retail chains for small and marginal farmers by storing produce for a few days.

7.4.2 Improved Methods/Modern Storage Methods/ High Cost Storage Technologies

Several improved and novel packaging and storage technologies are available including refrigerated storage, controlled atmospheric storage, modified atmosphere packaging and hypobaric storage. Important considerations for commercially adopting these technologies for bulk-level include cost effectiveness, eco-friendliness, product quality and applicability range, storage area to product volume ratio, skill requirement, process control, energy requirement, and safety aspects. Some improved storage technologies for horticultural crops are discussed below:

7.4.2.1 Cold Storage: A cold chain guarantees and ensures the quality maintenance right from harvest to the consumer use and cold storage facility **(Figure 11)** is the heart of the cold chain employed in the marketing of fresh produce. Cold storage is a storage space maintained with the help of a non-toxic refrigerant and the walls insulated with a good insulator, like poly urethane foam (PUF) to minimize heat loss. An adequate storage option is ensured by cold storages that maintains the desired conditions of fresh produce storage combined with ventilation systems and humidity controllers.

In modern cold storage facilities, care is being taken to delay or inhibit the development or appearance of chilling injuries during the storage period of sensitive horticultural produce. Storage parameters like changes in temperature, gaseous composition or relative humidity control the incidence and extent of chilling injuries. They are employed most commonly at the industrial level; for example, pre-treatment at high temperatures, conditioning at moderate temperatures, treatments with CO_2 before or during storage, intermittent warming and storage in controlled atmospheres (CA) or modified atmospheres (MA).

a) **Controlled Atmosphere Storage (CA Storage):** In a CA storage system produce is kept at reduced O_2 and high CO_2 concentrations with suitable range of temperature and RH. The shelf life of many products can be extended up to 2-4 times longer than normal cold storage. The composition of CO_2 and O_2 levels in controlled atmosphere storage is kept within maintained and controlled levels in gas tight containers or stores. The metabolic activity of the ripening fruits and leakages in the walls prompts a continuous change in the gas composition of the storage space. The gas mixture will constantly change due to metabolic activity of the respiring F&V in the store and leakage of gases through doors and walls. The gas composition is thus monitored periodically and fresh air or nitrogen is input to maintain a predetermined level. It can also be done

Figure 11: Cold Storage

Source: Elansari et al., 2019

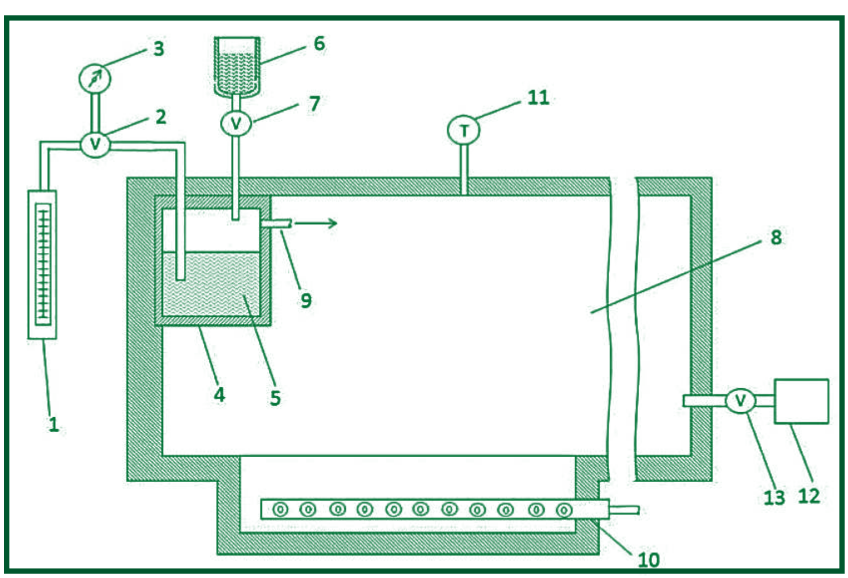
by passing the store atmosphere through a chemical to remove CO_2. Systems may be designed which use flushing initially to lower the oxygen content then either injecting carbon dioxide or allowing it to cumulate up through respiration, and then maintenance of this atmosphere by scrubbing and ventilation (Khan et al 2017). CA storage is commonly used for the bulk storage of many fruits.

b) **Modified Atmosphere Packaging and Storage (MAP Storage):** It includes packaging and storage of fresh produce in environments whose gas composition has been modified as compared to that of air to enhance keeping quality, shelf life and to lower the metabolic rate of the produce stored (Coles et al., 2003). The modified atmosphere packaging of fresh F&V includes replacement of the gases in the package headspace with a composition of gases that are non-reactive at their composition and different to that of air. A composition of CO_2, O_2 and N_2 is injected in to the headspace that replaces the atmosphere. The nature of fresh produce determines the composition and amount of gases being used. Some of the key factors affecting the effectiveness of MAP storage are respiration rate of crop, permeability of the packaging surface, O_2 and CO_2 permeability of package material, storage temperature and volume of headspace present inside the package (Sultana et al 2015). MAP can be classified as being passive and active condition:

i. **Passive MAP:** In passive MAP, rate of respiration of crop and packaging film permeability are the most significant parameters. Food material utilise a portion of oxygen to respire and produce CO_2 inside the packet. After some time, gas composition in the headspace of the package reaches a definite balance between respiration rate and permeability of packaging film. In equilibrium state, the total amounts of CO_2 produced and O_2 consumption by respiration are equal to that permeated through the membrane surface.

ii. **Active MAP:** In active modification, the atmosphere of the package is evacuated and replaced with a desired gas composition to ameliorate gas composition modification and to avoid stress induced due to exposure to high gas concentrations.

Figure 12: Schematic Diagram of a Hypobaric Storage Unit: (1) Airflow Chamber, (2) Needle Valve, (3) Vacuum Gauge, (4) Humidifier, (5) Distilled Water, (6) Water Reservoir, (7) Valve, (8) Storage Chamber, (9) Conduit, (10) Refrigeration Unit, (11) Temperature Gauge, (12) Vacuum Pump, (13) Throttle Valve



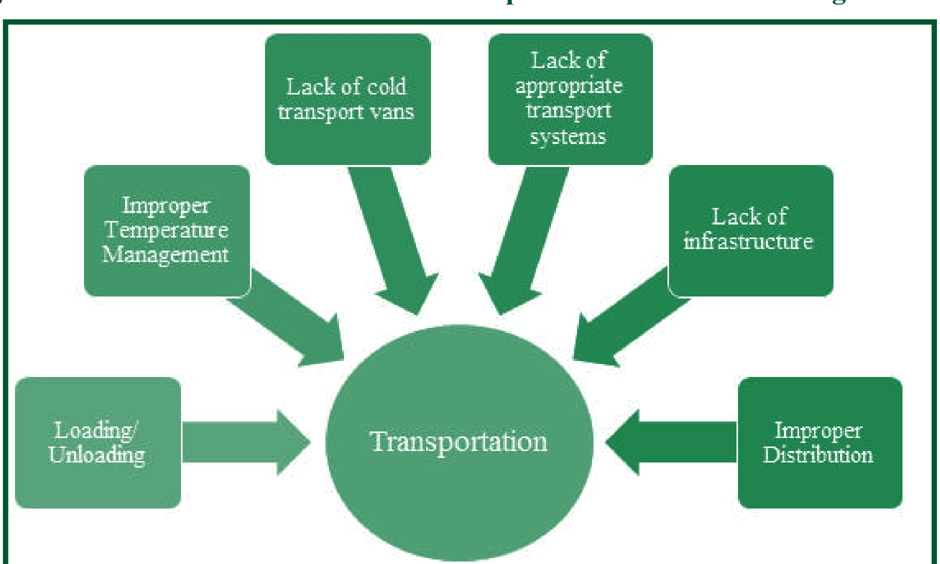
Source: Vithu & Moses, 2017

7.4.2.2 Hypobaric Storage/Low Pressure Storage: Hypobaric pressure or sub-atmospheric pressure refers to pressure below atmospheric pressure. Hypobaric storage is a type of controlled atmospheric storage in which low-oxygen environment is created by low pressure inside the packet, which reduces the respiration rate and metabolism activities. A typical hypobaric system consists of a produce storage chamber, a vacuum pump, a refrigeration unit and a humidifier **Figure 12 (Page 45).** Generally, a reduction in air pressure of 10 kPa (equivalent to an oxygen partial pressure of 2.1 kPa) permits 2% reduction in oxygen concentration at normal atmospheric pressure (Vithu and Moses 2017). Air enters the system through the airflow chamber and a needle valve is used to regulate the incoming low pressure air using a vacuum gauge. Air enters in a humidifier to increase the RH to about 80-100%. Water from a water reservoir is added to the humidifier with the help of a valve. The humidification system removes respiratory heat thereby preventing water loss. Saturated air is supplied to the vacuum storage chamber through a conduit. Storage temperature is an important parameter and is kept under control (-2 to 15°C) using a refrigeration unit. A temperature gauge shows the variation in temperature during storage. To ensure maintaining low pressure in the storage chamber, a vacuum pump is provided. A pressure regulator/throttle valve controls the entry/exit of air from/ to the system. This technology is at pilot scale at present.

7.5 Transportation

Proper transportation of crops from the farm to the market is essential in reducing PHLs. This can involve the use of proper packaging and transportation methods, including cold chain. Mechanical injury during transportation often leads to considerable quality loss. Transportation is a major bottleneck in the marketing chain for F&V. Limited availability of suitable storage compromises quality and leads to considerable wastage. Mitigating these problems would necessitate education of producers and distributors; improved control of transportation, distribution and storage of F&V; building a suitably integrated fruit and vegetable chain for cooling, transportation, sorting, grading, storage, packaging and marketing of F&V in different regions of the world **(Figure13).**

Figure 13: Problems Associated with Transportation of Fruits and Vegetables



Source: Compiled by Authors

There are three main causes of the loss of F&V. **First**, the good original quality of F&V reduces the loss, which depends on the harvest and post-harvest methods. If the proper harvest method is applied, the proper postharvest method should be applied as well. Training of labour may lead to use of proper harvest and post-harvest methods. **Second**, high temperature during storage causes high loss. **Finally**, the compression and impact causes the loss. There are four main causes of these compression and impact, such as location of container in the truck, loading method, types of vehicles and road condition. The upper location of truck, the few axle vehicle and poor road condition can increase the compression and impact while the proper loading method reduces the compression and impact.

7.6 Livestock Produce

The slaughter/dairy processing waste contain nutrients like nitrogen and phosphorus, and wastewater could be the source of energy. In most of the developing countries, efficient and eco-friendly management of waste is needed. Some of the future technologies are discussed here.

7.6.1 Cultured Meat Production

Cultured meat is the meat produced by growing muscle cells in a media rather than rearing the animals and slaughtering them. The cultured meat production process involves the isolation of cells from the biopsy, cell culturing in a specific medium, cells differentiation on scaffolds, and scaling up of process in the bioreactors. Tuomisto and de Mattos (2011) reported that the cultured meat may results in 78-96% less GHG emission, 99% less land requirement, 82-96% less water requirement, and 7-45% less energy need in comparison to conventionally produced meat from different sources. Cultured meat can contribute significantly to meeting the animal protein requirements of the ever growing population. The concept holds potential to help in combating the negative effect on the environment caused by livestock and meat production. However, safety aspects of the product need to be ensured by putting proper checks at various levels from production to consumption. This technology is at pilot scale and a few commercial units are also available.

7.6.2 Bio-Plastics from Sludge

Bio-plastics are biodegradable material produced by microbes using carbohydrates and lipids with elimination of the higher cost compared to conventional plastic. Polyhydroxyalkanoates are produced by microbes through the fermentation of carbohydrates and lipids. Polyhydroxyalkanoates are produced by plants and bacteria, like *Cupriavidus necator*, *Bacillus spp., Alcaligenes* spp., *Pseudo-monas spp., Aeromonas hydrophila*, *Rhodopseudomonaspalustris*, *Escherichia coli*, *Burkholderia sacchari*, and *Halomonas boliviensis* are also involved in polyhydroxyalkanoates production (Verlinden et al., 2007). Sludge obtained from the effluent treatment plant and slaughterhouse is a prospective source for the segregation of microorganisms. The technology is at laboratory stage.

7.6.3 Microbial Fuel Cell

Microbial fuel cells are novel bioreactors used for the generation of electrochemical energy using exoelectrogenic biofilms. The anaerobic microbes oxidize the substrate/organic matter and generate electrons and protons. The electrons go to an anode, pass through an external circuit and produce current while protons travel to the cathode and form water by reacting with oxygen and electrons (Sekar et al., 2019). The waste water from the slaughterhouse can produce power density of 578 mW/m^2 (Katuri et al., 2012). It may be a very important technology in the future to meet the demand for electricity in an eco-friendly manner.

7.6.4 Bio-Hydrogen Production

The microbial metabolism may be a potential source for bio-hydrogen for large-scale production. For the production of bio-hydrogen, direct water, solar photosynthesis/bio-photolysis or anaerobic fermentative process approaches are used. Out of the above mentioned technologies, fermentative hydrogen production is the most appropriate technology. Further research and developments are essential for scaling up the production in a cost-effective manner. (Mullai et al., 2016).

7.6.5 Rendering

Rendering is a process in which waste animal tissue and by-products are converted into saleable commodities, such as high-quality fat and protein products for the production of animal feed, soap, paints and varnishes, cosmetics, explosives, toothpaste, pharmaceuticals, leather, textiles, lubricants, biofuels and other valuable products. Rendering is an energy-intensive process, has a limited application, and majority of tissue processed comes from slaughterhouses in the form of fatty tissue, blood, bones and offal, as well as entire carcasses.

The rendering process involves grinding of animal products, which is not used as food, to uniform size and then heated to a specified time at specific temperature combination to thoroughly cook the material. Fat is separated from the protein due to the heat, which is segregated by centrifugation and ready for use. Protein is pulverized again to make a consistent protein meal.

Rendering uses heat and pressure that sterilises and stabilises animal material, kills harmful microorganisms, and prevents any further decomposition of by-products and makes them suitable for storage and reprocessing for other uses. A key step is removing water. Only a proportion of the feedstock is turned into material, the rest is lost as water which is treated for safe return to the environment. In the UK there are around 2 MT of animal by-products sent to rendering plants (Parry et al., 2015).

7.6.6 Gasification

Gasification as a technology has been slow to develop, with few waste gasifiers operating globally, especially at the scales required to deal with municipal solid waste. Gasification process converts organic materials (e.g. biomass, food wastes, animal by-products) into a combustible gas called 'Syngas', by reacting the material at high temperatures (>700°C) with a controlled amount of oxygen and/or steam. The syngas is usually comprised of carbon monoxide (CO), hydrogen (H_2) and Co_2.

Thermal gasification takes place in a reactor called gasifier. Before entering the gasifier, the waste is pulverised to a suitable size and dried to low moisture content. The waste should be also free from other undesirable materials, such as stones or metals, which could cause operational problems. Gasification is an intermediate step between pyrolysis and combustion, which is a two-step endothermic process. During the first step the volatile components of the material are vaporized at temperatures below 600°C by a set of complex reactions. No oxygen or other reactive agent is needed in this phase of the process. Hydrocarbon gases, H_2, CO, CO_2, tar and water vapour are the component in the volatile vapours. Char (fixed carbon) and ash are the by-products of the process. In the second step, char is gasified through the reactions with O_2, steam, CO_2 and/or H_2. In some gasification processes, some of the unburned char is combusted to release the heat needed for the endothermic gasification reactions.

8. ADVANCEMENTS IN FOOD WASTE MANAGEMENT IN THE WORLD AND CHALLENGES

With the development of newer technologies and advancements in processing, some new processes have been developed to enhance the shelf life of perishable food products.

8.1 Novel Alternate Processing Techniques

8.1.1 Irradiation

Ionizing radiation, mostly gamma-ray, has been used in many countries to preserve F&V. Irradiation is a process of exposing packed or unpacked F&V to carefully measured amount of intense radiating energy (ionizing radiation) like X-rays, ɣ-rays or electron beams etc. Cobalt-60 is the most commonly used source of irradiation. This technology is very promising in stopping potatoes from sprouting during long-term storage. There are several cases of applications of food irradiation. For each application, it is necessary to find the range of optimum dosage needed to obtain the desired effect. Too high a dosage can produce undesirable changes in texture, colour and taste of foods. Irradiation can also increase the shelf-life of foods in many ways by minimizing the number of spoilage organisms. It can be utilized as surrogate to chemicals to prevent sprouting as ionizing radiation interferes with cell division, and thereby extends the shelf life of potatoes, onions and garlic. Rate of ripening in F&V is slowed down when it is exposed to irradiation and can also be used as substitute to chemical fumigants for disinfestations of grains, spices, F&V. Many countries cut-off the import of products on suspicion of contamination with live insects to safeguard the importing country's agricultural base. Since most of the chemical fumigants are being banned, irradiation provides an alternative to promote the international shipment of food products.

8.1.2 High Pressure Processing (HPP)

F&V value added products processed by high pressure (150-600 MPa) are high quality food with greater safety and enhanced shelf life. The treatment can be less deleterious than thermal processes to low molecular weight food compounds, such as flavouring agents, pigments, vitamins, etc., as covalent bonding are not affected by pressure. The advantages include longer shelf life with retention of taste and nutritional properties of fresh F&V. Depending on the product, shelf life can be multiplied by 2 to 8 times while sensorial and nutritional properties remain intact. HPP has a high potential for development of new functional products. It can be used for processing F&V having antioxidant properties. Functional molecules that are destroyed by heat, can be preserved using HPP. Further, pathogenic and spoiling microorganisms are destroyed and cross-contamination is not viable because of post packaging nature of the process. The commercial application of HPP technology in developing countries will depend on the economic feasibility of the process. The capital cost associated with the equipment, particularly pressure vessels, and installation is an important hurdle for its commercial implementation. It is unlikely that pressure processing may replace canning or freezing, nevertheless it could find applications for expensive foods with short shelf lives and high value ingredients such as flavours, vitamins and functional biopolymers that are heat sensitive. HPP is not a low-cost technology, and a systematic approach must be taken to search for processing options to ensure that this technology can be successfully and economically applied to a wide range of products.

8.1.3 Ozone Processing

Ozone is the tri-atomic form of oxygen and is a highly efficient disinfectant. It is a safe, super effective disinfectant and oxidizer, control undesirable organism growth in equipment used in food processing industries. It does not work as a systemic poison to microorganisms, but relatively, eliminates them through oxidation process. It is not possible for a microorganism to establish any resistance to oxidation as it is 50 times more powerful and over 3000 times faster acting than chlorine bleach. Ozone processing has been used efficiently within the food industry for fresh F&V using either by gaseous treatment or washing with ozonised water (Aslam et al., 2020). Different application methods such as, spraying, bubbling, dipping of produce in dissolved ozone or storage in gaseous ozone have been used.

8.1.4 Ultrasonic Processing

One of the faster developing techniques devised to minimize processing time, improve quality and maintain the safety of food products is ultrasonic method. Sonication is a non-thermal technology in which sound waves having >18 kHz frequency are applied for processing and preservation of food without affecting the nutritional quality (Aslam et al., 2021). It is applicable to large-scale commercial applications, such as emulsification, homogenization, extraction, crystallization, dewatering, low-temperature pasteurization, degassing, defoaming, activation and inactivation of enzymes, particle size reduction, extrusion, and viscosity alteration. It is used in maintaining both pre- and post-harvest quality attributes in fresh F&V and is also contemplated as an alternative for cleaning of F&V in food industry. In an endeavour to realize the consumer needs of not only preserving but also enhancing the nutritional value of fruit juices ultra-sonication is the most competent method as this technique retains fresh quality, nutritional value, and microbiological safety in juices. Ultra sonication cleaners (20-400 kHz) have been effectively used to yield contamination free F&V.

8.1.5 Pulsed Electric Field (PEF) Processing

Pulsed electric field (PEF) is an innovative non-thermal food processing technique that can penetrate cells in F&V tissues without a significant rise of temperature in the product averting excessive deterioration of the tissue. It uses a short, high voltage pulses for plant cells disintegration and microbial inactivation. The performance of PEF to irreversible penetration of cell membranes confide in process parameters (electric field strength, treatment time, specific energy, pulse shape, pulse duration/width, frequency, treatment temperature) and on the treated food characteristics, including food physicochemical properties (pH, electric conductivity) and cell characteristics (size, shape, membrane, envelope structure). The inclusive efficacy of PEF is a function of the sum of all of them. In soft plant tissues or materials, as the mesocarp or pericarp of most fruits, electric field ranged between 0.1 and 10 kV/cm are enough to augment PEF-induced cell membrane penetration. In hard materials where the lignification can occur (e.g., seeds, stalks), the effects in these electric fields are null. PEF processing is advantageous in several ways such as improvement in process yield, speeding the process time, quality enhancement (e.g. reduce fat uptake, reduce impact on sensory properties, increase health-related compounds), minimize the intensity of other processing variables (e.g. temperature, grinding degree), and increase in the cost effectiveness of the operation. PEF technology is commercially available, however, it is used for limited foods.

8.2 Food Waste Treatment through Composting or Anaerobic Digestion

Anaerobic Digestion (AD) is a series of biological processes in which microorganisms digest plant or animal material in sealed containers, producing biogas (mixture of methane, CO_2 and other gases) (US EPA, 2014). The organic material left over, known as digestate, is rich in organic matter and nutrients such as nitrogen, phosphate and potash. Biogas and digestate are therefore both important outputs of AD.

The difference between AD and composting is that anaerobic digestion occurs within containers in the absence of oxygen, whereas composting, or aerobic digestion, requires oxygen. It is estimated that 580 kg CO_2 eq. can be saved for each ton of food waste diverted from landfill to an anaerobic digester when the resulting biogas is used to replace natural gas (Ellen MacArthur Foundation (2013).

9. QUALITY AND SAFETY REGULATIONS, POLICIES AND THEIR IMPLICATIONS ON POST-HARVEST LOSSES – SOME EXAMPLES

Quality standards for food products are made to ensure that safe and quality food are available to the population. Governments, food industries, and people should be aware, and regulatory options may be formulated to encourage prevention of FW and reduce the environmental, economic, and social problems caused by FW. Each country has its own population behaviour, culture, with its unique food products, and logistics. Each individual has his unique preference for food and hence regulations and strategies to prevent FW are made accordingly. Some of the regulations being formulated worldwide to reduce FW are discussed below.

9.1 Waste Framework Directives of European Union (EU)

The EU is adopting changes to the Waste Framework Directive in a series of policy revisions known as the **Circular Economy Package.** It is included in the Directive and actions are required from member nations to implement waste prevention policies and to report back to the European Commission on their efficacy. Further, an obligation to separately collect FW by 2023 and an aspirational target to reduce FW within the EU by 2030 by 50%, have been adopted. The specific features are:

9.1.1 Good Samaritan Law

In order to facilitate redistribution of surplus food and to address the legal obstacle, governments have passed "Good Samaritan" laws, which limit the liability of donors in case redistributed food turns out to be somehow harmful to the consumer unless there has been gross negligence (https://www.law.cornell.edu/uscode/text/42/1791). The law enables donors and food banks to serve more people and reduce FW.

9.1.2 Tax Credits and Tax Deductions for Food Redistribution

Multiple European countries including France, Germany, Greece, Italy, and Poland give tax and fiscal incentives for the donation of food as a goodwill gesture and to encourage donations. For example, in Italy, value added tax is not imposed on food that is donated. Similarly, in France and in Spain, a proportion (35-50%) of the value of donated food can be deducted from the taxable revenue of the donor enterprise (European Economic and Social Committee, 2014).

9.1.3 Food Date Labelling

While some date labels on food bought from grocery stores refer to food safety (for example, 'use by'), others are targeted towards food quality (for example, 'best if used by' and 'display until'). Meanings of these labels are often unclear to the consumers and leads to FW that is still edible and safe to consume. There was a call for action by the Consumer Goods Forum to standardise food labels worldwide by 2020 (The Consumer Goods Forum, 2017). This included using only one date label on a product and educating the consumers on its meaning via in-store displays, web service and public service announcements. Standardisation of labels is likely to have a widespread impact on reduction of FW generated by households, supermarkets, and establishment selling packaged food.

9.1.4 Supermarket Food Waste Recovery Requirement

Regulatory requirements, such as banning the destruction of edible food by addition of water or bleach unless it poses a real food safety risk, may be enacted to encourage redistribution and energy/nutrient recovery from the food (NRDC, 2015).

9.1.5 Banning of Organic Waste to Landfills

EU Landfill Directive obliged the member countries to reduce the amount of biodegradable waste going to landfill to 35% of 1995 levels by 2020 (European Commission, 2016). Some EU member states (Germany, Austria and Sweden) have gone further and banned all FW to landfill. Along similar lines, commercial establishments generating organic waste in excess of a predetermined threshold may be required to recycle it, if such a facility exists within a certain distance. This encourages businesses to reduce FW in the first instance.

Such laws have also been enforced in some states of USA (Massachusetts and Connecticut) and also in the City of Vancouver, Canada.

9.1.6 Pay-As-You-Throw (PAYT)

PAYT schemes charge the producers of FW for the disposal of the waste they generate based on the weight/volume of waste. Seoul (South Korea) has reported 10% reduction in FW generation after implementation of such a collection method (Waste Management World, 2017). PAYT schemes have a direct impact on the profit or expenditure of the business or household and are an effective tool for FW prevention, as well as contributing towards the funding of collection/treatment. This tool, however, needs strict monitoring to prevent illegal dumping or fly tipping.

9.2 Food Waste Prepared and Treated to be used as Animal Feed

The FW hierarchy suggests that the next best option, if it cannot be prevented and is not suitable for human consumption use it as animal feed. Depending on the proximity of FW generators to local farms or zoos, it may be viable to recover discarded food as feed for livestock, poultry, or other animals. Some food scraps, such as coffee or foods with high salt content, can be harmful to the animals, and regulations pertaining to the types of FW that can be used vary from place to place (USEPA, 2014b). Some examples on using FW in animal feed are given below:

- **In the UK** food manufacturing establishments use around 2.2 MT of food or food by-products as animal feed. Regulations and standards are in place to ensure food safety and protection of animal health (Parry et al, 2015).
- The most popular method of reusing food waste in **Vietnam** is feeding it to livestock, particularly to pigs in smallholder farms in peri-urban areas. Household kitchens, food processing establishments, and food processing plants produce a huge amount of avoidable uneaten food that contains cellulose, hemicellulose, lignin, protein compounds and nutrients that are beneficial to pigs. Pigs can therefore play an important role in FW management, as they can eat and digest different food types and are considered FW collectors (CIRAD, INRA, 2015).
- **In Egypt** the Zabaleen community collects FW from households to feed pigs. The Zabaleen are Coptic Christians and therefore eat pork, but this is at times a conflicting issue in mainly Muslim nations (Eplett, 2013). Cultural and religious beliefs and practices should be taken into account when considering FW use in animal feed. The reluctance of farmers to feed FW directly to their pigs for the fear of transmission of disease can be overcome by cooking the FW before feeding it to the animals, producing what is colloquially known as "swill" (Ermgassen, 2015).
- **Japan and South Korea** respectively recycled 35.9% and 42.5% of their FW as animal feed. In these countries, the industry is strictly regulated and the heat treatment of FW is carried out by registered "Ecofeed" manufacturers, who are required by food safety law to heat/treat food waste containing meats for a minimum of 30 minutes at 70°C or 3 minutes at 80°C. In Japan and South Korea, swill is seen as a strategic resource and is a cheap, domestic alternative to the more expensive, volatile international market for grain- and soybean-based feeds (Ermgassen, 2015).

While FW as animal feed has been historically used for pigs, it can, be fed to other species also. A number of studies have been conducted using FW diets for poultry, fish, insects, and ruminants (cattle, goat and sheep).

10. POLICY INTERVENTIONS FOR REDUCING POST-HARVEST LOSSES IN DIFFERENT REGIONS OF WORLD

10.1 General Policy Framework for Developing Countries

Ever increasing human population is the main reason for the requirement of additional food and hence preventing FLW is unavoidable to fulfil the ever-increasing demand. Further, this burdens the natural resources also. Therefore, the first policy should be to control the human population growth, particularly in the developing countries as defined by FAO (2011).

Many studies discourage over concentration on single or few policies to reduce the FLW. Even though the individual interventions recorded positive returns, the very nature of agriculture means that complementarities could result in returns that will be much higher than the returns of individual policies. Some of the points to be considered for developing countries are:

- **Building local knowledge of value chains** for comprehensive loss assessment and innovations identification.
- **Establishing repository of harvest and post-harvest machineries of high capacity** (Combine harvester, thresher, grader etc.) at production catchment level for custom hiring so that farmers may complete the operations in time.
- **Setting up cold chain for perishables,** which is in demand at present and has excellent prospects for the future, and irrespective of investment the cold chains for perishables should be setup.
- **Adopting holistic approach.** Promoting cultivation of particular type of crops in specific areas should be complemented with processing and marketing facilities.
- **Investment in infrastructure and public goods** to reduce losses and to ensure sustainable food systems such as storage and processing facilities, reliable energy supply, transport, appropriate technologies, improved access and connection of food producers and consumers to markets.
- **Taking collective actions with involvement of private sector** is crucial for reducing losses. Companies should be mobilized to change their practices in order to reduce losses at household levels.
- **Preparing advisories for farmers to use proper scientific methods** of harvest and post-harvest operations for each crop and region specific is crucial. These should be popularized.
- **Adopting smart harvesting, grading and packaging tools, equipment, technology** for extraction of high value bioactive compounds from F&V residue.
- **Improving technologies for effective utilization and eco-friendly disposal** of wastes and by-products should be undertaken.

10.2 Good Post-Harvest Management Practices

Good post-harvest management practices which can help in reducing FL in a food processing facility are given in **Table 11 (Page 54).** The adoption of such practices at each unit operation would ensure a minimum post-harvest loss and maximize the economic outputs of producers.

Table 11: Good Post-Harvest Management Practices

Management Point	Correct Practice	Minor Adjustments Implemented	Need of Examining Practice	Improvement is Essential: Prioritize Changes
Good Agricultural Practices (GAP)	GAP is followed.	GAP is followed in combination with traditional practices.	Some GAP practices are followed .	GAP is not followed at all.
Harvesting at Right Maturity	Following maturity standards at the time of harvest; harvest from natural point of break; use of clippers with saver; use of proper containers.	Harvest earlier, when produce are delicate; harvest later, when fruits are at a riper, more flavourful stage; or multiple harvest; follow maturity standards.	Harvest all crop at a time; use of tree shakers; heaping harvested produce in the field; faulty use of clipper.	Harvesting is not done at right maturity.
Collection of Harvested Produce	Use of appropriate clean containers; No overloading; Use of pushcart; Use of appropriate cushions.	Use of locally made containers and cushioning material.	Use of inappropriate containers; overloading at some occasions; heaping in the field and filling in containers.	Heaping in the field; Use of flexible containers (gunny bags; plastic pouches etc.) for collection.
Curing of Root and Tuber Crop in the Field	Curing as per recommended practices.	Use of temporary structure/ method in bad weather conditions.		Improper curing method.
Dirt/ Soil Removal from Produce and Containers in the Field (To avoid Contamination of Wash Water or other Loads (after Unloading in Pack House)	Dust/ dirt/ soil are removed from produce and containers in the field. Containers are cleaned and sanitized prior to sending back to field.			Containers are frequently moved into the packing area without inspection.
Water Quality for Washing of Produce or/ and Making Ice	Use of potable water for washing the produce and making ice from a municipal or ground water source. Annual water tests.	Water quality for washing produce or making ice is not tested, but the source is farm drinking water supply.	Water is from a ground water source that has not been tested.	Water is not potable or it is from a surface water source.
Water Quality Management in Tanks, Flumes, Hydro-Coolers, or other Batch Water Tanks	Wash water is changed 4-5 times a day; chlorinated/ disinfected; levels are monitored to maintain suitable pH (6.5-7.5).		Water is changed 2 times in a day. Disinfectant is added and pH is adjusted monitored after every 1-2 h.	Disinfectants are not used. Water is changed periodically based on visual assessment.

Continued...

Management Point	Correct Practice	Minor Adjustments Implemented	Need of Examining Practice	Improvement is Essential: Prioritize Changes
Temperature Management of Water in Dump	Regularly monitored to be no more than 10°C cooler than produce. Standard Operating Procedure (SOP) is followed.	Frequently monitored to be no more than 10°C cooler than produce.		Water temperature is not monitored.
Ice Storage and Handling	Ice reservoirs are cleaned and sanitized monthly; no direct hand contact with ice. Cleaning schedule and records are kept.	Reservoirs are cleaned and sanitized twice in a season. No direct hand contact with ice. Records of cleaning dates are kept.	Reservoirs are cleaned and sanitized only once (beginning of the season). No records are kept and there is no ice handling policy.	Reservoirs are not cleaned or sanitized. No ice handling policy exists. Use of farm tools or hands.
Backflow Devices and Water Source	Backflow devices are installed separating dump and flume tanks from the water source.			Backflow devices are not installed.
Cleaning and Sanitation of Containers used in Harvesting, Handling, Packing and Shipping	New containers are used for packing. Previously used containers are inspected, washed, rinsed and sanitized prior to each use.	Previously used containers are inspected and washed, rinsed, and sanitized prior to each use.	Used wooden or plastic bins or boxes are washed, rinsed and sanitized occasionally based on visual assessment of cleanliness.	Used wooden or plastic bins or boxes are not washed or sanitized.
Storage of Containers	Containers are stored in covered and isolated area from the packing area; bins are not exposed to rodents, dust, or condensation.	Containers are stored in the packing area, off the ground and preferably, under plastic cover.		Containers are stored in open, on the floor, exposed to dust and animals or outside.
Cold Chain Maintenance to Minimize Pathogens Growth	After cooling, the produce is placed instantly in cold storage until sale or shipping. Refer vans are used for shipping. Produce temperature is monitored and recorded.	Cooled produce is maintained at requisite temperature in storage. Refer vans are used for shipping. Temperature record is not kept.	Cooled produce is stored in packing areas until sale. Refer vans are not used.	Cold chain is not maintained.
Cleaning of Temperature Controlled Produce Storage Area	Storage areas are cleaned daily, washed and sanitized regularly. SOPs are in place for sanitation, and records verify implementation.	Storage areas are cleaned weekly but not sanitized on a schedule. SOPs are there but not verified regularly.	Storage areas are cleaned only periodically. No SOPs in place.	Storage areas are cleaned only once at the beginning of the season.

Continued ...

Management Point	Correct Practice	Minor Adjustments Implemented	Need of Examining Practice	Improvement is Essential: Prioritize Changes
Refrigerated or Cold Storage Loading and Management	No overloading of cold storage. Wet produce is not stored above dry produce, and condensation from coolers does not drip onto produce.	Overloading for limited period. Wet produce is not stored above dry produce and coolers do not drip on produce.	Overloading of cold storage occasionally. Wet produce is sometimes stored above dry produce.	Improper arrangement of containers in cold storage. Overloading and water dripping onto produce.
Transportation of Produce	Refer vans/ trucks are used to move produce at optimum cold -chain temperatures, monitored and recorded.	Refer vans/ trucks are used to move produce at optimum cold - chain temperatures, monitored but not recorded.	Refer vans/ trucks are used only for shipping produce longer than 2 h.	Refer vans/ trucks are not used.
Sanitization of Shipping Truck	Prior to loading produce, the vehicle is inspected for cleanliness, odours, and debris; cleaned and sanitized. Records are kept.	Prior to loading produce, vehicle is inspected for cleanliness, odours, and debris, rinsed when needed. Records are kept.	Vehicles are inspected and appear clean, no washing or sanitizing is done. No records are kept.	Not inspected for cleanliness. Produce is just loaded. No records are kept.
Trace-Back and Record Keeping	Trace-back system is implemented. All harvested and shipped produce is coded by field, harvest date and crew; records are maintained in proper format for easy access.	Trace-back system is implemented. All harvested and shipped produce is coded by field, harvest date and crew. Records are not maintained in a format for easy access.	Partial trace -back system is implemented. Records Are only kept for some produce depending on the market.	No records are kept of produce to allow tracking of practices or trace - back.
SOPs and Record Keeping to Attention to Food Safety Risk Management	SOPs are in place for washing, cooling, storage and shipping. Record keeping includes routine verification of practices.	SOPs and record keeping in place, but verification is done periodically.	SOPs in place, but no records are kept to verify actions.	No SOPs or record keeping for reducing food safety risks.
Good Manufacturing Practices (GMP) for Processing and Value Addition	GMP is in place for the unit; licensed; Food certification; testing and other standards are followed.			Unregistered unit.

Source: Compiled by Authors

11. RECOMMENDATIONS

Different government organizations, National/International research institutes and universities, private sectors and non-governmental organizations (NGOs) etc. have been involved and have played certain roles in PHL management. The key intervention required all along food chains to reduce FLW are:

- Conduct country diagnostics to identify priority commodities, hot spots (of high rates of FLW) and stages of intervention for reducing FLW.
- Develop FLW databases to support more detailed behavioural investigations and to monitor progress. The work of Waste & Resources Action Programme (WRAP) in the UK shows ways to develop the information needed.
- Develop a menu of potential interventions that are technically and politically feasible, and include financial and economic analyses of the interventions.
- Define roles of the public and private sectors, as well as the roles of horizontal and vertical levels of Government.
- Define the complementary role of FLW reduction in the context of strategies that address other policy goals, such as improving the environmental footprint of food systems, addressing food security, or improving farm welfare.
- Consider the need to rely on safety nets, including unconditional and conditional cash transfers, to support some of the policy goals of reducing FLW or potential negative impacts that may result from them.
- Develop sources of financing and financial instruments to support private and public FLW reduction action, including support for research and knowledge-based organizations.
- Include FLW reduction in nationally determined contributions (NDCs) for climate mitigation, and in sources of climate mitigation financing.
- Consider instruments to sustain financial support for FLW reduction, including taxes on waste or non-recovery.

12. SUMMARY AND CONCLUSIONS

In the last decade, the global attention towards reduction of postharvest FLW has increased considerably, while several national and international projects and organizations have included postharvest loss assessments in their agendas. Different PHL assessment methodologies including interviews, sampling, and hybrid methods were adapted by various workers around the world, but most were ad hoc, designed by an individual researcher and used only once or twice. Many studies considered for the review did not have some of the important details such as sampling method for quantitative measurements, size of the sample, process of data collection, survey population size, and analysis method to estimate the losses. More than 50% of recent PHL studies were carried out in South Asian and SSA regions. PHL studies conducted in different African nations included 27 different crops compared to 45 different crops and livestock produce in South Asia, mainly in India. Most of the PHL studies provided quantitative losses data, while few included reported on qualitative and economic loss measurements.

Reporting PHLs is a complex phenomenon and the extent of losses reported may differ depending upon the region selected and the consumer acceptance of the product in that region. The very wide range of the extent of FLW from 0 to 80 % in different crops and livestock produce depends upon many factors such as the physiology of crops, disease incidence, time of harvest, temperature, weather conditions, packaging, duration of handling and storage, etc. Fewer studies reported the qualitative losses data and most of these studies were done on perishable crops. PHL in terms of economic losses were rarely reported despite involving a relatively simple calculation based on market values. Some of the studies also represented PHL in terms of nutritional losses or carbon footprint due to losses, but these were very few in number.

Several conventional and newer technologies have been developed for processing, value addition, and storage of foods. These technologies may be helpful in reducing the losses and ensure quality food supplies throughout the year. FW is equivalent to PHL, which is a serious concern from social, environmental, economic and management point of view. Several policies and framework have been formulated by different countries to reduce FW. However, the awareness is less among consumers about FW. Further, increasing human population is the main hurdle in reducing the volume of FLW, and it is burdening the natural resources across the globe. A single or few policies may not be helpful in reducing the losses and holistic approach is essential. In summary, the following challenges comes in the way to understand and prepare plan to reduce FLW:

- Non-uniform non-standard methods to estimate FLW.
- Not setting goals to reduce the FLW in a planned manner.
- Increasing food quality and safety concerns in the absence of strict regulations.
- Poor consumer awareness and acceptance.
- Technological scalability and adoptability.
- Lack of Good Post-Harvest Management practices.
- Limited policy framework and private investment particularly in low-income countries.

While addressing the massive challenge of reducing FLW, following points may be considered:

- Systematic FLW data collection in developing and developed countries to identify the critical points of FLW.
- Policy framework for each country on circular economic model.
- Improvements in supply chain using advance energy efficient green technologies.
- Creating consumers awareness about the impact of FLW and their responsibilities.
- Work in collaboration with private investors to develop efficient food supply chain to reduce food loss.

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Dr. Nachiket Kotwaliwale is an agricultural engineer with degrees from JNKVV, Jabalpur, Rajasthan Agricultural University, Bikaner, (Campus: CTAE, Udaipur) and Oklahoma State University, Stillwater, USA. He joined Indian Council of Agricultural Research in 1993 as a scientist and subsequently became Head of Agro Produce Processing Division at ICAR-CIAE, Bhopal, and presently working as Director of ICAR-CIPHET, Ludhiana, India with additional charge of Director, ICAR-NRC Makhana, Darbhanga. His major areas of professional interest are design of agro processing machinery, computer aided design and design analysis, non-destructive quality evaluation of agro produce, sensor and machine vision applications in agriculture, instrumentation for quality and safety in agro processing.

Dr. Kotwaliwale has published about 12 books/ proceedings, around 100 publications including research papers and popular articles. He also has five software copyrights and two patents in his name. He has guided three masters' dissertations, and three doctoral students. He has conducted several training programmes in Agro Processing, Image processing, Non-destructive quality evaluation, Food safety, Agro produce loss prevention and value addition, etc. For his professional contributions, he has been conferred with 'ISAE-Fellowship' and 'Eminent Agricultural Engineer Award' by the Institution of Engineers (India). He is Member of Board of management of two state agricultural universities and one Institute of National Importance. He has declared no conflict of interest.

Dr. R. K. Vishwakarma

Dr. R. K. Vishwakarma is All India Coordinated Research Project on Post-Harvest Engineering and Technology, CIPHET since May 2023, which has 30 centres across India. He is serving as Lead Centre Platform Coordinator (LCPC) of Consortium Research Platform Project (CRP) on Secondary Agricultural since 2018. He is the testing Authority of Post-Harvest Machinery and Equipment Testing Centre (PHMETC) at ICAR-CIPHET, Ludhiana since 2021 and has tested more than 200 post-harvest machines. Dr. R. K. Vishwakarma is Project Coordinator,

Dr. Vishwakarma has handled several Project of National importance, such as Post-harvest loss assessment studies in 2005-2009 and 2013-2015, Norms to quantify grain loss during storage for Food Corporation of India (FCI), Norms for milling outturn of pulses for Department of Consumer Affairs, Protocol for storage of food grains for FCI, Fumigation chamber design for Export of Grapes, etc.

He has developed complete mechanized line for makhana processing, guar processing, millets processing, litchi processing, etc. He has 8 patents granted and has licensed several machines and products for commercial manufacturing. He has more than 35 Research publications in international journals. He received NRDC Award in 2015 for developing makhana popping machine. He has declared no conflict of interest.

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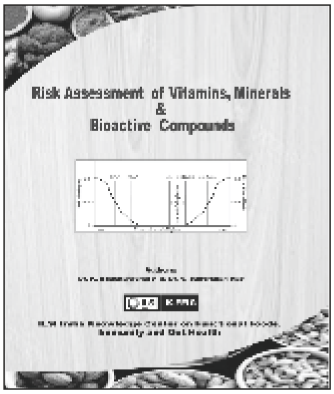

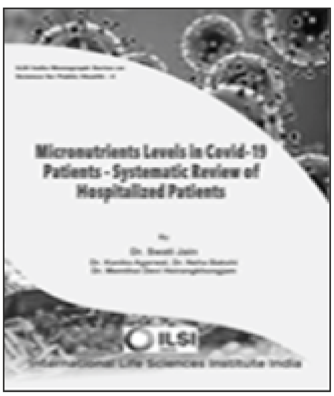

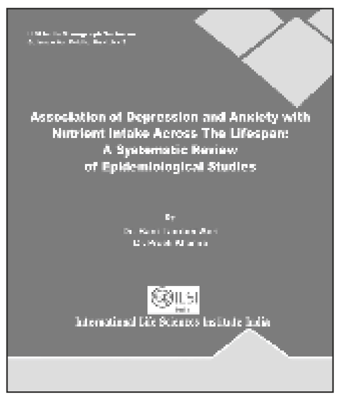

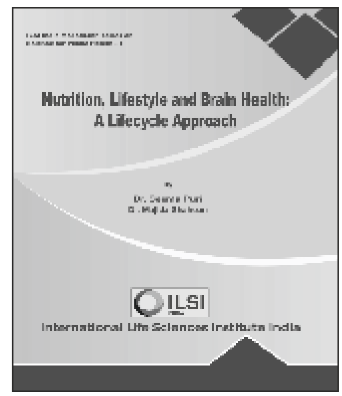

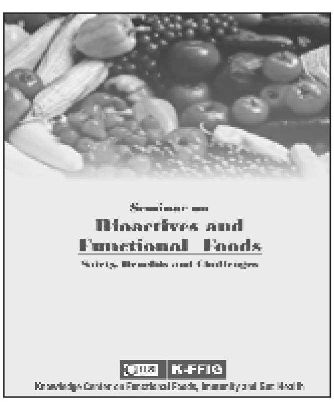

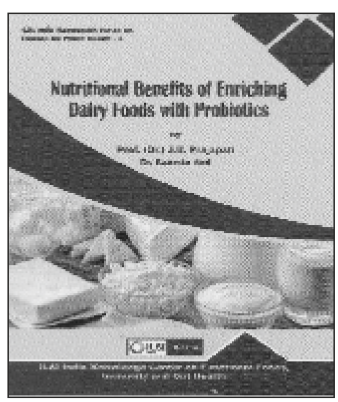

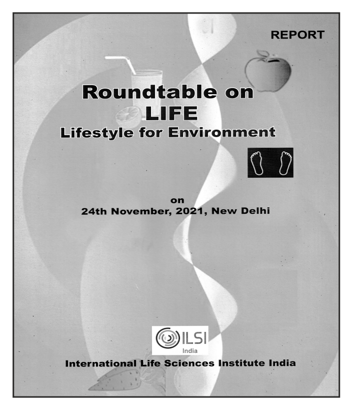

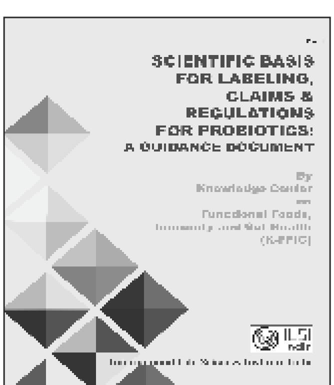

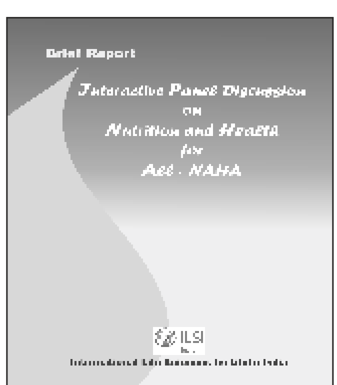

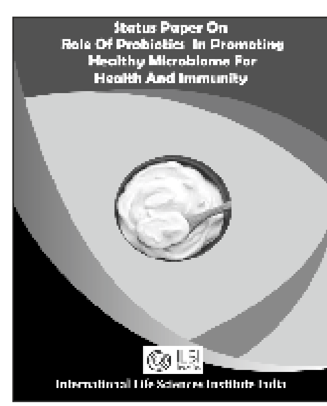

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