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REVIEW OF MAJOR GRAINS POSTHARVEST LOSSES IN ETHIOPIA AND CUSTOMIZATION OF A LOSS ASSESSMENT METHODOLOGY

November 2018

Addis Ababa, Ethiopia

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Agricultural Knowledge, Learning, Documentation and Policy Project (AKLDP-Ethiopia)

Cover Photo 1: Mobile multi-crop thresher in Aoromia (Zewai), 2016, Ali Ibrahim
Cover Photo 2: Hermetic Storage – Metal Silo, 2018, Ali Ibrahim
Cover Photo 3: Traditional Threshing in Amhara Region, 2017, Ali Ibrahim
Cover Photo 4: Stacked Maize, 2018, Abraham Tadesse
Cover Photo 5: Threshing floor in preparation, Amhara Region, 2017, Ali Ibrahim
Cover Photo 6: Traditional store (Gota) in Amhara Region, 2017, Ali Ibrahim

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Suggested citation:
Mohammed, A. and Tadesse, A. (2018). Review of Major Grains Postharvest Losses in Ethiopia and Customization of a Loss Assessment Methodology. USAID/Ethiopia Agriculture Knowledge, Learning, Documentation and Policy Project, Addis Ababa.

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This study was funded by USAID under AKLDP, contract number AID-663-C-14-00002. AKLDP is implemented by the Feinstein International Center, Friedman School of Nutrition Science and Policy, Tufts University. The study team acknowledges the support of AKLDP in designing the study, providing resources, and assisting with field work.

TABLE OF CONTENTS

List of tables in Appendix

ACKNOWLEDGEMENTS

We would like to duly acknowledge the Government of the United States of America for providing us with funds to undertake this assignment that is timely and yet neglected for various reasons.

The team would like to thank the Agriculture Knowledge, Learning, Documentation and Policy Project (AKLDP), Feinstein International Center, Friedman School of Nutrition Science and Policy at Tufts University for providing us with the opportunity to undertake this task. Particular credits go to Dr. Berhanu Admassu and Dr. Fentahun Mengistu for their guidance at every stage of the assignment and all the arrangements that were made to make the timely and successful completion of the task very smooth.

Credits also go to all institutions and individuals who contributed as sources of information with regard to postharvest research and development in Ethiopia and research methodology used, both at national and global levels.

GLOSSARY OF TECHNICAL TERMS

Agricultural value chain: a supply chain that comprises the activities of input supply, production, postharvest management, storage, processing, marketing, and distribution, or any other activity involved in the "farm-to-fork" continuum for a given product.

Assessment: the process of gathering information using various methods to systematically gauge the effectiveness of the domain.

Critical loss points (CLPs): stages or points in the food supply chain (FSC) where food losses have the highest magnitude, the highest impact on food security, and the highest effect on the economic result of the FSC.

Damage: the superficial evidence of deterioration, e.g., holed or broken grains, from which loss may result.

Drying grain: the practice of removing moisture from grain in order to lower the moisture content to a level recommended as safe.

Estimation: the process by which measured basic data are combined and interpreted; experience and judgment are combined during the process to bear on the factual data.

Food: any substance, whether processed, semi-processed, or raw, that is intended for human consumption.

Food loss: a decrease, at all stages of the food chain prior to the consumer level, in mass of food that was originally intended for human consumption, regardless of the cause.

Food security: as defined by the United Nations' Committee on World Food Security, is the condition in which all people, at all times, have physical, social, and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Food supply chain (FSC): the connected series of activities to produce, process, distribute, and consume food.

Food waste: refers to food appropriate for human consumption being discarded or left to spoil at the consumer level, regardless of the cause.

Harvest losses: losses that occur during the harvesting process and may be due to, for example, shattering and shedding of the grain from the ears to the ground.

Harvesting: the act of separating the food material from the site of immediate growth or production or the process of cutting, gathering, bundling, and stacking the crop.

Low loss points (LLP): points in the FSC where the losses are actually unexpectedly low.

Measurement: the reproducible procedure of extracting, recording, or mapping basic quantitative or qualitative facts about loss situations; "reproducible" implies that the same procedure applied by any operator under the same circumstances will yield the same outcomes.

Model: a simplified representation of the relationship between a phenomenon (variable of interest, dependent variable) to measure or explain and its explanatory factors (independent variables).

On-farm postharvest losses: are postharvest losses that may occur when grain is harvested, stacked, threshed, winnowed, dried, transported, processed, and stored at the production site.

Off-farm postharvest losses: are postharvest losses incurred along the chain during transportation, storage, marketing, and processing that usually occur in the hands of traders, processors, warehouse operators, etc.

Postharvest: the period after separation from the site of immediate growth or production.

Postharvest loss (PHL): measurable qualitative and quantitative food loss along the supply chain, including the production, harvesting, primary handling, aggregation, storage, transport, processing, distribution, and consumption segments.

Postharvest profile: a set of loss figures that represent each of links in the value chain.

Postharvest system: the delivery of a crop from the time and place of harvest to the time and place of consumption, with minimum loss, maximum efficiency, and maximum return for all involved.

Postharvest technology: interdisciplinary "science and technique" applied to agricultural produce after harvest for its protection, conservation, processing, packaging, distribution, marketing, and utilization to meet the food and nutritional requirements of the people in relation to their needs.

Post-production: harvest and postharvest combined. Often used as synonym for postharvest.

Qualitative loss: food that has incurred a reduction in economic value or nutritional value, but not in weight, and everything will be eaten by people; or when grain loses its quality attributes, resulting in the deterioration in quality leading to a loss of economic, social, and nutritional value.

Quantitative loss: the physical disappearance of grain from the postharvest supply chain and grain not consumed due to, among other causes, spillage, consumption by pests, and to physical changes in temperature, moisture content, and chemical changes during postharvest operations from farms to markets.

Storage: the art of keeping grains for some time in different containers or storage structures for later consumption or sale.

Study design: a plan that specifies which units should be surveyed and analyzed, their number (for example, the size of a certain sample), and how to select them.

Supply chain: a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer.

Threshing or shelling: the act of separating grains/seed from the husk/pod/plant to which they are attached.

Value chain: a set of activities that a firm or organization operating in a specific industry or supply chain performs in order to transform and deliver a valuable product to the market.

Winnowing: the process consisting of cleaning the grain by blowing the chaff away from it.

ACRONYMS AND ABBREVIATIONS

AGRA	Alliance for a Green Revolution in Africa
AKLDP	Agriculture Knowledge, Learning, Documentation and Policy Project
APHLIS	African Postharvest Loss Information System
C&W	Count and weigh
CLP	Critical loss point
CSA	Central Statistical Agency
DE	Diatomaceous earth
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural Organization of the United Nations
FGD	Focus group discussion
FLW	Food loss and waste
FSC	Food supply chain
FTC	Farmers' training center
FtF	Feed the Future
GDP	Gross domestic product
GIZ	Gesellschaft für Internationale Zusammensarbeit GmBH
GSARS	Global Strategy to improve agricultural and rural statistics
IAR	Institute of Agricultural Research
IPM	Integrated pest management
Kg	Kilogram
LGB	Larger grain borer
LLP	Low loss point
MoALR	Ministry of Agriculture and Livestock Resources
MoANR	Ministry of Agriculture and Natural Resources
MoARD	Ministry of Agriculture and Rural Development
NGO	Non-governmental organization
PHL	Postharvest loss
PHM	Postharvest management
PICS	Purdue Improved Crop Storage (bag)
PPSE	Plant Protection Society of Ethiopia
R&D	Research and development
RLAT	Rapid Loss Appraisal Tool
SG 2000	Sasakawa Global 2000
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SSI	Semi-structured interview
SVW	Standard volume weight
TGM	Thousand grain mass
USD	United States dollar
VC	Value chain

EXECUTIVE SUMMARY

A detailed review of published and unpublished literature on postharvest loss inflicted and loss reduction options available in Ethiopia for maize, sorghum, wheat, barley, teff, and haricot bean was made. A broad-based electronic article search, browsing of hard copies of theses and reports held by universities, research centers, ministries, and non-governmental organizations (NGOs) as well as personal communications were carried out. Moreover, articles pertaining to methodologies and approaches used for postharvest loss assessments, both nationally and globally, were reviewed.

Though it is not advisable to generalize about postharvest studies for different reasons, the average total postharvest losses (PHLs) ranged from 15.54 to 27.2%. Crop-wise, the average PHLs were 8.3–21.4%, 6.2–32.9%, 9.5–27.0%, 23.0%, 11.8–25.2%, and 16.3–21.0% for maize, sorghum, wheat, barley, haricot beans, and teff, respectively. In all cases, storage losses are very high, and the ranges in loss estimates are wide. Such variations are due mainly to the methodologies of loss assessment envisaged and at times due to the differences in study locations. As a result, reliable data pertaining to PHLs are still lacking, especially along supply chains of the different commodities. Most studies have identified the causes of PHLs to be the lack of appropriate and affordable technologies for the different operations, poor infrastructure, lack of awareness, lack of financial support for postharvest operations, tendency of the extension system to focus on pre-harvest operations rather than postharvest, etc.

Numerous options for reduction of postharvest losses in grain crops have been developed and recommended. These include cultural practices such as prompt harvesting, proper drying before storage, etc., use of resistant crop varieties, admixing grain with teff, finger millet, or inert dusts, use of hermetic storage containers, treatment of grain with pesticides, and use of combination of different compatible options in an integrated manner using integrated pest management (IPM)). However, more efforts are needed to utilize the existing technologies and to develop new, affordable, and more effective technologies to mitigate PHLs of the selected commodities based on a value chain approach.

Regarding postharvest loss assessment methodologies globally used, the review indicated different methods and approaches suggested for use, each having its own limitations. These include the Food and Agriculture Organization (FAO) 4-S, the rapid loss assessment tool (RLAT), the African Postharvest Loss Information System (APHLIS), count and weigh (C&W), standard volume weigh (SVW), thousand grain mass (TGM), converted percentage and visual scale (VS), and visual damage score (VDS) methods.

A customized methodology for assessment of PHL in grain crops in Ethiopia is recommended by combining the salient features of the different methodologies used in the world. However, the methodology is pending, awaiting validation and ground-level testing before adoption for general use. A more practical guide of loss assessment with detailed steps and data collection templates will be required to make use of the validated methodology. As the nature of horticultural crops is different from grain crops, it is imperative to consider relevant methodologies and develop a similar customized methodology appropriate for the Ethiopian context for horticultural crops.

I. INTRODUCTION

1.1 Status and importance of grain crops production

Grain crops (cereals and pulses) are the major food crops for the majority of the Ethiopian population, in addition to serving as sources of income at household level and contributing to the country's foreign currency earnings. Within the category of grain crops, cereals are the major food crops, both in terms of the area they are planted and volume of production obtained. They are produced in larger volumes compared with other crops because they are the principal staple crops. Tafesse et al. (2011) indicated that five major cereals (teff, wheat, maize, sorghum, and barley) are the core of Ethiopia's agriculture and food economy, accounting for about three-fourths of the total area cultivated, 29% of agricultural gross domestic product (GDP) in 2005/06 (14% of total GDP), and 64% of calories consumed.

According to a 2017 Central Statistical Agency (CSA) report, 12.57 million hectares of land were covered by grain crops and about 290.39 million quintals of grains were produced in private peasant holdings in 2016/17 (2009, Ethiopian calendar (EC)). The percentage of land area under cereals, pulses, and oil seeds was 81.27, 12.33, and 6.40%, respectively; and the percentage production was 87.42, 9.69, and 2.89%, in that order. Of the 81.27% of land covered by cereals, teff, maize, sorghum, and wheat contributed 29.53, 20.89, 18.42, and 16.59%, respectively. Regarding production, of the 87.42% contributed by cereals, the share of maize, teff, wheat, and sorghum was 30.91, 19.78, 17.88, and 18.72%, respectively. Of the 12.33% of land area and 9.69% production of pulses, the proportion of land covered by faba bean, haricot bean, and chickpea was 27.59, 18.72, and 14.56%, respectively. In terms of production, the proportions of faba bean, haricot bean, and chickpea was 31.19, 17.19, and 15.78%, respectively.

Tafesse et al. (2011) indicated that there has been substantial growth in cereals, in terms of area cultivated, yields, and production since 2000, but yields are low by international standards, and overall production is highly susceptible to weather shocks, particularly droughts. Much of the increase in production in the past decade has been due to increases in area cultivated. However, little suitable uncultivated land remains in the highlands, apart from pasture land. Soil degradation from erosion and soil compaction also threatens crop yields (Hamza and Anderson, 2005; Tadesse, 2001). Furthermore, uncertain rainfall and very low levels of irrigation make intensive cultivation with improved seeds and fertilizer risky (McCann, 1995). Hence, increasing production and productivity is faced with serious challenges in improving food security through ensuring adequate food availability and increasing household incomes (Tafesse et al., 2011).

1.2 The significance of postharvest losses in grain crops

To date, the attempt to ensure food security was made merely by increasing crop productivity and production in the field. However, increasing food production is being constrained by limited land and water resources and increased weather variability due to climate change (Aulakh et al., 2013). Regarding productivity per unit area, Ethiopia is far below average, even by some African standards.

On the other hand, a huge amount of losses occurs at different stages after crops are harvested and before consumption, after a large investment of time, labor, and money in the production process. Kaminski and Christiansen (2014) estimated losses to be as high 37% in sub-Saharan Africa. A recent report by Kumar et al. (2017) indicated that more than one-third of food is lost every year in the postharvest operations. In Ethiopia, data on losses at different stages in the postharvest system are limited, although storage losses are relatively better studied. One earlier report estimated that crop losses of 2 to 3%, 1 to 2%, 4 to 6%, 2 to 5%, and 1 to 3% occur in cereals during cutting, drying, threshing, winnowing, and transportation, respectively (Anon., 1993 cited in Tadesse et al., 2008). From a study conducted in West Gojam Zone, Tadesse and Regassa (2013) reported losses in the major stages of the postharvest system ranging between 30–50%. According to AGRA (2014), postharvest losses of all the crops in Ethiopia have been estimated to be between 10 to 50%. FAO (2016) estimated postharvest loss of maize, sorghum, wheat, and haricot bean to be approximately 21.4, 32.9, 18.4, and 25.2%, respectively.

However, these losses occurring in the postharvest system have not been given the attention they deserve and have even been neglected for a long time (Tadesse et al., 2008). Many authors in the postharvest sector realize that appropriate postharvest management (PHM) is the missing link between production and consumption (Kitinoja et al., 2011), contributing significantly to the food insecurity problem.

Furthermore, postharvest losses cause not only loss of the economic value of the food produced but also the waste of scarce resources such as labor, land, and water, as well as non-renewable resources such as fertilizer and energy, all of which are used to produce, process, handle, and transport food (FAO, 2011). Solutions to reduce postharvest losses require relatively modest investment and can result in high returns compared to increasing the crop production to meet the food demand (Kumar et al., 2017). Therefore, along with continued efforts to increase production and productivity, it is recognized that PHL reduction can provide an environmentally sustainable and cost-effective contribution to food security and income improvement, compared to a sole reliance on increasing production in a world with limited natural resources, and in an era of high and volatile food prices (FAO and World Bank, 2010; Aulakh et al., 2013).

In order to effectively reduce postharvest losses, it is first necessary to know the scale of these losses across the different stages, to know which steps are the critical points for losses, and to identify the causes that can be controlled and improved in the whole postharvest process. However, efforts to identify and resolve the critical issues along the value chain (VC) in many sub-Saharan African countries, including Ethiopia, are impeded by the lack of a simple, adoptable, and well-defined practical methodology on how to estimate quantitative and qualitative postharvest losses. This makes it impossible to have credible data during the various operations along the value chain (Kumar et al., 2017).

Hence, the effort of any attempt to develop a methodology should be to produce a guideline on the precise, time-saving, effective, and lowest-cost way of estimating grain postharvest losses. In this way, development of customized postharvest loss assessment methodologies that are regionally and globally deployed could contribute to better planning, designing, and targeting of loss reduction interventions. This is because effective investment in PHL mitigation requires a clear knowledge of the magnitudes of the losses, the drivers of these losses at each stage, and the cost of mitigation (Chegere, 2017).

Therefore, the purpose of this study was to review and compile losses reported to date and loss reduction options recommended and loss assessment methods in use globally, and customize appropriate methodologies that can be used in Ethiopia as a working document for formulation of a nationally harmonized and validated systematic PHL assessment guideline/framework.

1.3 Objectives of the study

The objectives of the study were:

- Review and document available in-country information on losses in the grain crops post-production system and identify best technologies and practices recommended locally;
- Customize workable loss assessment methodologies that would provide standardized and reproducible results so that quality data are generated for sound decision-making and implementation of effective loss reduction measures.

2. THE STUDY APPROACH AND METHODOLOGY

The terms of reference (TOR) given to the team include review of losses of grains in Ethiopia, loss management options, review of available methodologies being used globally, and customization of suitable method/s for Ethiopia. The general framework, depicting the methodology followed for desk review of available domestic information on losses in the post-production system of gains and methods used for their assessment as well as development of customized postharvest loss assessment methodologies, is described.

In the review process, a huge effort was exerted to collect and review quite a substantial volume of available published and unpublished (printed and electronic) literature on both postharvest studies and loss assessment methodologies. Documents reviewed date back as far as the 1960s and are as recent as 2018. The whole set of documents was divided into two groups, namely documents that focused on specific topics relating to PHL assessment studies with their related methods and techniques, and those documents that covered general PHL topics. Based on the scope of the task assignment, the review gave greater emphasis to documents of the first category, though the latter was used for an overall description of the domain and its concepts.

The review of PHL and loss assessment methods in use as well as the customization of loss assessment methodologies intentionally focused on grain crops, with particular emphasis given to maize, sorghum, wheat, barley, teff, and haricot bean. This is based on the rationale that these crops have higher food, nutrition, and economic importance at the national level.

Given the variabilities in terms of agro-ecology, social setup, and the postharvest system, the review and customization of global PHL assessment methodologies were done for Ethiopian conditions. The following activities were performed to accomplish the task.

2.1 Review of PHLs and practices in the postharvest system

- Assessed background on the postharvest system.
- Conducted comprehensive review on the type and extent of PHLs of major grain crops.
- Identified the stages of the value chain where the studies were conducted.
- Identified the methodologies used for the studies, when available.
- Identified challenges documented in research and development (R&D) interventions.
- Documented development interventions and best technologies/practices recommended.

2.2 Customized crop post-production loss assessment methodologies development

- Described the postharvest system and domain.
- Undertook a thorough in-country and global methodological review.
- Recommended appropriate customized methodology for the Ethiopian context.
- Validated findings at a stakeholders workshop.

3. MAJOR FINDINGS

3.1 Postharvest operations and associated causes of losses in grain crops

The main stages within the agricultural supply chain during which losses occur in grain crops and the associated causes of losses may be distinguished as indicated below. The African Postharvest Losses Information System (APHLIS) uses the following stages for its postharvest loss profile: harvesting, platform drying, threshing and shelling, winnowing, transport to farm, farm storage, and transport to market and market storage. This chain is for food grains only and does not include the consumption stage.

Harvesting

The time of harvesting is determined by the degree of maturity. It affects successive operations, particularly threshing, winnowing, storage, processing, and preservation. The optimum time of harvest for grain crops is when the grain reaches physiological maturity at a moisture content of 20–30% (World Bank, 2011). Nonetheless, Ethiopian farmers commonly harvest most crops after physiological maturity is attained and when the moisture content reaches as low as 13% or below (Ashagari, 2000). This helps to dry the crop in the field and gives farmers adequate time during the overlapping operations in the peak activity time that compete for labor. It is obvious that harvesting too early or too late has its own consequences. While late harvesting results in extended pre-harvest field drying, which may ensure good preservation, it also heightens the risk of loss due to different reasons. The longer the harvest remains standing in the field, the greater the risk of loss due to shattering before harvest; physical grain loss due to incomplete harvesting of straws consists of lodging loss (ears will fall on the ground) and standing straw loss; rain will encourage the spread of molds; animals (birds, rodents, monkeys) will take their share, while insects such as weevils and bruchids will lay eggs in the grain that will continue to do damage during storage. Poor farmers at times harvest crops too early due to food deficiency or the desperate need for cash. In such instances, the food incurs a loss in nutritional and economic value and may get wasted if it is not suitable for consumption.

Farmers determine the right time of harvesting based on their long-established practices that are based on the crop calendar, color change of leaves, harvestable parts, and texture of the seed or kernels. They attempt to reduce loss at harvest by timely harvesting before the crop is too dry to shatter before or during harvesting. This is particularly important in the case of wheat and haricot bean, which are highly susceptible to shattering loss.

Once the time of harvesting is decided, then the exact time is scheduled based on weather conditions in the area. Harvesting is preferably done during dry weather in order to avoid losses due to mold development. In case of haricot bean, harvesting is performed in the early morning and/or late afternoon.

Wheat harvesting is often done manually, with the exception of places like Gedeb Hassasa (Oromia) and Debre Elias (Amhara), where combiners are used to harvest and thresh simultaneously. More than 80% of farmers in Gedeb Hassasa and Debre Elias do both harvesting and threshing at the same time using hired combine harvesters. A negligible percentage (less than 20%) of farmers in these areas use manual sickle-based harvesting and oxen-trampled threshing.

Maize harvesting follows two methods. In some places, harvesting is done by detaching the ears from the stalk standing in the field (either de-husked or left in sheaths). Maize is harvested by cutting the stalks by sickle and stacking them with ears in the field in an upright position for some time for further drying. Causes of losses at this stage are: (i) detachment of some ears off the stalks while cutting and stacking; or (ii) missing of ears during collection to the drying area; or (iii) delayed harvesting leading to attacks by insect pests, rodents, wild/domestic animals, and mold.

Harvesting of teff is carried out by grasping the teff plants in one hand and cutting them with a sickle near the base of the plant. In some parts of Ethiopia, such as in the central part of the country, farmers crouch and cut the plants near the soil surface, especially when the teff plants are short. In other parts of the country, the whole plant is pulled out (Refera, 2001). After the plant is cut and placed on the ground, other people, usually the elderly, women, and young children, follow the harvesters and tie the harvested plants in small bundles or sheaves called *nedo*. These are 14 to 18 cm in diameter and are bundled with green teff plants: the sheaves are larger if bundled with green sorghum stalks. Other farmers, instead of tying the plants into sheaves, leave them loose on the ground. The sheaves or loose plants are subsequently stacked in the field, where they remain until the farmer has finished harvesting all of his crops in other fields (Refera, 2001). The harvested teff crop is then carried on the women's backs, men's shoulders or heads, and/or on a donkey to near the threshing ground in the village where a large stack or pile, called *kimir*, is put on stone or bare ground (Refera, 2001) for subsequent threshing by trampling with cattle on the manure-smeared threshing ground.

Sorghum panicles are cut off, leaving the stalk standing in the field for animals to graze on the best of the residual leaf material; or the stalks are cut and stored for use as dry season animal fodder, or for house construction and fencing. Manual harvesting involves cutting the crop and then gathering and bundling it. Although this operation can also be done with a mechanical harvester, almost all farmers in Ethiopia use manual labor to harvest their sorghum fields.

Haricot bean is generally harvested when the leaves and pods turn a yellow or straw color, by pulling up the whole plant. The crop is rarely harvested using a sickle. When a sickle is used, the harvester holds the crop and cuts it to the soil level. Once the plants are pulled up or cut, they are left in rows of small heaps (*nedo*) in the field for further drying.

The physical loss of grain during harvesting occurs at three points: (1) cutting of the straws due to grain shattering and incomplete cutting; (2) intermediary piling (field-in-staking) of the harvested straws in small mounts temporarily as harvesting continues; and (3) transportation of the straws to a suitable stacking point.

Farmers in some areas reported that they attempt to reduce harvesting loss by timely harvesting, before the crop is too dry to shatter during cutting. Harvesting is also timed to coincide with dry weather as wet harvesting results in great losses. Tying the harvest crop in small bundles or sheaves is important to reduce loss (some farmers do not tie). The harvest is stacked in the field and remains until the farmer is ready to thresh (Tadesse and Regassa, 2013).

Staking and field drying

Haricot bean is collected and piled on animal skin (hides) canvas or other locally available material and tied in sheaves. The sheaves then are transported either to the stacking place or directly to the threshing yard by animal power and/or manpower. Farmers may or may not stack haricot bean. Farmers who stack haricot bean lay a foundation made of stones or plant material for piling the haricot bean. The cut crop is stacked loose without a definite pattern on the foundation material. Since the crop is stacked loose, it is always liable to damage if unseasonal rain occurs. During stacking, losses may be incurred due to grain dropping/shedding or scattering during piling (stacking). Moreover, field drying on stacks for several weeks before threshing exposes the crop to several factors that cause losses; e.g., damage by animals (wild and domestic), insects such as termites, storage insect pests, grain mold, etc.

Most farmers are quite familiar with the fact that further drying is very important for both effective threshing and good storage without mold development. For this reason, farmers at times leave their harvested crops stacked in the field or move them to the threshing floor where the harvest is left to dry until threshing is due to take place. Stacking is done in such a way that the heads are upside down and covered with empty stalks in order to prevent damage by rain and consumption by domestic and wild animals. Stacks may also be built on a stone base in order to avoid termite damage.

The length of time needed for full drying of ears and grains depends considerably on weather and atmospheric conditions. If the grain is not dry enough, it becomes vulnerable to mold and can rot during storage. On the other hand, if grain is too dry, it becomes brittle and can crack after threshing or during hulling or milling, if milling takes place a longer time (two to three months) after the grain has matured, thus causing heavy losses. Farmers rely almost exclusively on natural sunshine and moving air for drying of crops; consequently, cloudy and damp weather conditions at harvest time can be a serious cause of postharvest losses.

Unless under large-scale commercial farms, there is no scenario where producers determine the optimum drying time with the use of a moisture tester. Rather, they depend on biting by teeth and the gritty sound and hard texture of the harvest in the hand feeling test. WFP (2012) suggested the use of the salt method as a very cheap alternative to check whether the grain is sufficiently dry and safe to store. The salt test is conducted as follows: (i) fill a clean dry jar/glass bottle with salt, to the 1/4 full level; (ii) add the seeds to reach the 1/2 full level and close the lid, sealing tightly; (iii) shake the jar/glass well and leave for 10 minutes. If after 10 minutes there is damp salt adhering to the inside of the jar, the seed is still moist (above 15% level) and will need further drying. If there is no salt adhering to the inside of the jar, the seed is adequately dry for storage.

Threshing/shelling

In the Ethiopian context, the common methods of threshing under small-scale farmers' conditions are: (i) manually using hands, mainly for maize (shelling); (ii) manually beating with sticks; (iii) animal trampling; and (iv) at times pounding with mortar and pestle. However, the most common method is animal trampling (Alemu, 2016). With the exception of shelling of maize by hand (stripping with fingers, rubbing two cobs against each other, rubbing cob on rough stone, beating cobs or bagged cobs with sticks), such traditional practices cause much loss to the grain's physical quality, scattering of grains out of the threshing floor, and contamination with waste of trampling animals.

Usually, the threshing ground is prepared by smoothing the ground and smearing it with cattle dung. The floor is compacted by wetting with water and driving cattle over it before plastering it with cow dung. When the floor gets dry, the cut crop is spread over it for threshing. Stones are also laid around the threshing floor to prevent scattering of grain and straw. Whenever the crop scatters outside the threshing floor, it will be swept back to the floor using a threshing fork. Animal droppings are collected and thrown out of the threshing floor.

During threshing/shelling, the grains are separated from the husk (in the case of small cereals) or from the cob (in the case of maize). This operation can be done manually or mechanically by threshers. Shelling maize is done by hand (women and children), but it is tedious and labor consuming, with low productivity. Maize shelling is difficult at moisture content above 25%. Grain stripping efficiency will be very poor, with high operational energy and mechanical damage to the kernels. A more efficient shelling is achieved when the grain is dried to 13–14% moisture content.

In recent years, some threshing/shelling machines suitable for small-scale operations like maize shellers have been introduced in several places in Ethiopia. The Sasakawa Global 2000 (SG 2000) program has been demonstrating multi-crop threshers of different capacities to farmers and service producers. Adoption of motorized threshers is increasing, and maize producers are very keen to get the service.

Losses during threshing may occur due to: (i) incomplete threshing (grain remains on the straw); (ii) direct damage (breakage) to the grain or weakening of the seed coat, which leads to grain that will be more susceptible to pests in storage; or (iii) spillage and scattering during the process; and (iv) consumption of grains by animals used for trampling purposes. Qualitative losses due to grain contamination with soil, animal droppings, and urine are equally as important as quantitative losses.

According to Tadesse and Regassa (2013), threshing loss of cereals is minimized by preparing a good (smooth and adequately wide) threshing ground, using muzzles for trampling animals to avoid eating of the crop, collecting the droppings of animals before they fall on the threshing ground, making sure that all grains are separated from the straw (a well-dried crop will thresh well), and threshing as promptly as possible.

Cleaning/winnowing

Cleaning/winnowing involves separating the grain from dirt and chaff/straw by throwing/tossing the chaff-grain mixture in the air to separate the seeds from the chaff. A wooden fork, usually with three or four prongs, is used to separate the grain and straw. A further way of winnowing is carried out by raising a container full of grain and chaff above the farmer's height and letting it drop smoothly so that the blowing wind will separate the seeds from the chaff. Lighter-weight broken grains, straw, and weed seeds are carried by the wind to one side, as the whole and sound grain falls to the bottom of the winnowing device. The operation requires a continuous brisk wind and several repetitions. The remaining chaff and dirt are removed by fanning with a "*sephed*" (a flat plate made of grass and used for separating grain from the chaff) and by sieving and hand picking.

The traditional way of threshing and winnowing leads to contamination of grains with foreign matter (pebbles, dirt, and cow dung) and loss of grains due to the foreign matter dropping in to grains and the wind blowing grains away with chaff. Some innovative farmers have started to use canvas or plastic sheeting on their threshing and winnowing floor to minimize these risks. After cleaning, farmers pack their grain in jute bags, *silcha* (bags made of leather), or polypropylene bags of different capacities, often 50- or 100-kilogram (kg), and make the clean and finished harvest ready for transportation and storage.

Drying

Harvested crops must be further dried at the farm yard for safe storage. Drying is a critical step to maintain the crop quality, minimize storage losses caused by insects and micro-organisms, and reduce transportation costs.

Grain can be contaminated with pieces of straw chaff, broken grains, stones, and dirt when it is spread on the threshing floor for further drying. Use of mats or plastic sheets for spreading the grains reduces contamination with dust and makes the collection of grains easy.

Losses during grain drying may occur due to birds, rodents, insect pests, and other animals. Grain molds cause severe damage to inadequately dried grain. The recommended moisture content for safe storage of most grains is 13% or below. Moisture meters are used to determine the optimum moisture content of grains. The use of the salt technique that simply indicates whether the moisture content of the grain is less than 15% was suggested (WFP, 2012).

Storage

As crops are grown seasonally, storage for certain periods of time as food reserves and as seeds for next season or sale is mandatory. Small-scale farmers in Ethiopia retain 60 to 90% of the total grain produced for subsistence and store it for 6 to 12 months (Tadesse et al., 2008). Grain storage losses are the most studied stage in the postharvest system, and most of the reports indicate that maximum losses occur at this stage of the postharvest system in Ethiopia. Different crops are stored in different forms and different types of storage structures/containers.

There are several storage technologies available for grains. The choice of the particular type depends on the scale of production, crop type, prevailing climatic conditions, and the farmers' ability and willingness to pay.

Farmers in the different parts of Ethiopia use different traditional storage containers (indoor or outdoor). These include *gotera, gotta*, (also known as *dibignit, gumbi, godo, gushgush*), *keffo* (*togogo, kirchat, schirfa*), *golota, meaqen, walla*, jute or Hessian sacks, skin bags (*aqomada/loqota, aybet*), clay jars, gourds, wooden boxes, metal drums/barrels, and underground pits (Tadesse et al., 2008). Some of the traditional storage containers such as clay jars and gourds have capacities of a few kilograms and are generally used for storing small amounts of seed in the house (Tadesse, 1991; 2003). Farmers store maize and sorghum in different forms: maize on the cob, with or without husks, or shelled, or in combinations of different forms. Sorghum is also stored on the head (without threshing), threshed, or as a mixture of both forms. The form of grain to be stored determines the method and type of storage containers to be used. Shelled or threshed grain is stored in a container plastered from the inside and may be treated with insecticides. Suspending cob maize and head sorghum from the ceiling over the fireplace, under the eve of the roof, or on tree branches in the field are also commonly practiced methods of storage (Tadesse, 1991).

Gotera (above-ground bin) is the most commonly used storage container in most parts of the country. It is located outdoors. It is usually a cylindrical structure, flat or conical at the base, placed on a raised platform or stones, and covered with a conical thatched roof. The size of a *gotera* can vary depending upon the volume of production, and the capacity is usually between one and four tons (IAR, 1990b, in Tadesse et al., 2008). Bins without plastering are used for storage of unshelled maize, which requires further drying. *Gotha, gumbi, dibignit, godo*, and *gushgush* are names given to similar types of containers (capacities may vary) in different parts of the country. These are typically made of mixtures of mud, cow dung, and teff straw. Their sizes vary, and they are usually kept indoors. The small ones are made of a single piece, whereas the big ones (with a capacity of more than three tons) are usually made of rings (known as *dengel* in some localities) stacked one above the other so that the vessel can be taken apart and reassembled elsewhere. It may have a grain outlet spout in some localities. *Keffo, togogo*, or *kirchat* are also similar to the above, but these are usually made of split reeds, bamboo, or twigs and may be plastered with cow dung from the inside. They are kept indoors or outside abutting the wall of the house. They are similar to *gotta* in shape and may also have a spout at the lower side for grain withdrawal. In some areas in the vicinity of Jimma, farmers store unthreshed crops in sheaves on straw placed in the granaries. Grains such as sorghum and maize are stored underground in some parts of the country (Lemmesa, 2008; FAO, 2017 unpublished), but it is unusual for teff to be stored in such pits (Tadesse, 1969, cited by Refera, 2001).

During a recent baseline study by FAO (2017, unpublished), it was observed that in areas like Alamata of Tigray, Derashe of Southern Nations, Nationalities, and Peoples' Region (SNNPR), and Fedis of eastern Oromia, sorghum is stored in underground pits of two- to six-ton capacity. Underground storage pits can be constructed outside or inside of farmers' house. Farmers have different criteria that they use to select a place to make storage pits. These include: closeness to residences; security against theft; choice of a more raised place to avoid leakage or percolation of moisture during rainy season; soil type and property, etc.

Packaging

This activity can be an important step for grains or their processed products. Packaging can be discussed from different perspectives, and in any case losses occurring due to defects in the methods of packaging and handling of grains deserve due attention. Within the context of the postharvest value chain, losses at this stage do not seem important in all cases. As most farmers fill their packaging material (bags) on the threshing floor, this stage is normally excluded to avoid double counting. Losses associated with packaging of grains for market are rarely considered important and are difficult to measure.

Transport

Transport operations may occur between the farmer's fields to the threshing floor and to farm storage, from the farmer's storage to assembling markets, or from assembling markets to mills; all of these operations entail loading and unloading. The distance of transportation may vary from several hundred meters to many kilometers away. There are different ways to transport harvested crop from the field to its destination. Depending on the volume of the harvest, the grain is packed in different packing materials such as jute sacks, plastic bags, or locally prepared containers (skin bags) and transported on human heads or backs (mostly women and children) to the storage or market places. When there are large volumes to be transported, pack animals like donkeys or horses and carts are used. During each movement, the concept of loss would normally be the weight of grain lost because of spillage.

Processing

This a stage that is often neglected or not treated as part of the postharvest stage in the value chain. Processing losses can occur on or off the farm depending on the structure of the value chain and can be the result of a manual process (for example, hand pounding) or a mechanical process (such as milling using hulling machines). Several processing operations can be carried out, depending on the crop and the practices. Typical operations involve de-husking, milling, and grinding of grains. At this stage, grain loss is normally expressed as a reduction in the quality of the finished product, although there may be some physical loss of grain through spillage. Losses due to scattering and spilling during processing stages can be measured by collecting and weighing the grains remaining on the ground. These losses are more significant for manual or mechanical processing at farm or village level than in specialized off-farm processing units.

Marketing

There are noticeable losses that can occur during marketing, both at wholesale and retail level. This is the final and decisive element in the postharvest system, and loss can occur during packaging, transporting, marketing, and market-level storage. However, care should be taken not to double count, as most of the activities attached to marketing are addressed in storage, transportation, or packaging.

3.2 Major factors causing postharvest losses in grains

A complex interplay of various factors contributes to the loss of grains that occurs in the post-production system. The losses within the system and at each stage/step of the value chain are most often attributed to the following elements or group of general factors: biological and/or microbiological; chemical and biochemical; and mechanical, environmental, and socioeconomic factors (GSARS, 2015).

Biological and microbiological: These comprise all losses due to pests of any sort that are capable of attacking undamaged grain (primary pests) as well as damaged grain (secondary pests). Insects, mites, rodents, and birds fall into this category. The larger grain borer (LGB) (*Prostephanus truncatus*), which is the most destructive insect pest of maize and cassava both in the field and storage, was recently introduced in Ethiopia. Losses caused by pests can be of both qualitative and quantitative nature, as food is consumed, damaged, or contaminated, especially during the storage period. Several species of fungi (molds, yeasts) also attack grains, some of them producing mycotoxins that can be detrimental to humans and animals (such as aflatoxin in groundnuts and maize).

Chemical and biochemical: Grains are alive, and chemical elements naturally present in stored commodities provide the basis for loss of nutritional value, flavor, texture, and color, for example through enzyme-activated reactions.

Mechanical and technical: The different farm operations that are carried out manually or mechanically (harvesting, drying, shelling, threshing, cleaning, bagging, transportation, etc.) can cause damage to the grain, which then becomes more vulnerable to enzyme-mediated chemical changes and to attack by insects and other pests during storage.

Environmental and climatic: High humidity levels and temperatures can trigger an alteration of certain biochemical processes such as oxidation and fermentation that can lead to a deterioration of the grain in storage. These processes can also be altered by the concentration of certain substances contained in the air surrounding the grain, such as oxygen, carbon dioxide, or nitrogen.

Socioeconomic: These include the nature of the equipment and facilities used at the different points of the chain, the way the different operations are carried out by the actors (production practices), as well as the conditions in which production takes place.

As these factors impact one another, they ought not be treated or analyzed separately. For example, climatic conditions (rain, temperature, humidity level, etc.) affect the physiological conditions of plants in the field or of the grain stored, as well as the degree of infestation by fungi, molds, and other pests (GSARS, 2015).

Some of these factors are related to the technologies, methods, techniques, and practices as they are deployed and used by the actors within the system, such as mechanization, agronomic practices, and farm management practices. Other factors relate directly to the natural environment, such as insects, molds, temperature, weather conditions, and humidity, or to the socioeconomic environment, such as access to market information. A given combination of any number of these factors may be at work at any given time to influence weight loss. Since these factors depend on the given stage/step within the value chain and many other variables, very few studies have used them. Climate conditions, the state of the grain at storage (presence of infestation, moisture content, and foreign matter content), the period of storage, and grain and pest control practices all contribute to the rate of loss caused by insects and mold growth. As indicated above, since these factors interact, it is difficult to isolate them or identify one factor that has a direct influence on loss.

The causes of food loss can also be classified into basic, underlying, and immediate causes. Each cause of loss is associated with symptoms and types of losses. The basic causes of grain PHL are associated with macro issues like the absence of supporting policies for PHM, poor infrastructure, shortage of trained human power in the area, and low economic capacity of the country. The underlying causes are related to absence of PHM service providers, lack/shortage of postharvest technologies, lack of awareness of farmers about the use available services and technologies, and lack of or limited postharvest extension services and market information. The cumulative effects of the above causes will lead to immediate causes of postharvest losses in terms of physical, mechanical, chemical, biological, and physiological dimensions. Each of these dimensions of losses is then observed in the food supply chain (FSC).

3.3 Postharvest loss of grain crops in Ethiopia

The importance of postharvest losses in developing countries has been recognized worldwide since 1975 when the United Nations General Assembly passed a resolution committing member states to reducing postharvest food losses by 50% by 1985 (Harris and Lindblad, 1978). In Ethiopia, limited studies were initiated in early 1960s by the Tropical Stored Products Research Centre, UK. In the early 1970s, Walker and Boxall (1974) did a comprehensive survey of insects, while efforts to reduce losses were also underway under Freedom from Hunger Committee (FFHC) (UNDP/FAO, 1982). Detailed studies were started by Ethiopian scientists in 1980s at Ethiopian Institute of Agricultural Research (EIAR), which came up with the identification and registry of storage pests. However, in Ethiopia, there was no research emphasis on the postharvest sector (except a few preliminary studies) until the late 1980s when some graduate students (e.g., Tadesse, 1991; Emana, 1993; Teshome, 1990) took the problem as their thesis research topics. Since then, several areas of research have been covered by different researchers in different institutions, although not in a coordinated fashion (Tadesse et al., 2008).

According to Tadesse et al. (2008), while research on other agricultural problems was handled by the then-IAR (Institute of Agricultural Research), the special problems associated with postharvest losses (PHLs) have been the concern of the Plant Protection and Regulatory Division of the then-Ministry of Agriculture (IAR, 1981, cited by Tadesse et al., 2008); though limited studies on storage pests were made in a staggered manner since early 1960s in some higher learning institutions (Hill, 1963 and Jimma Agricultural and Technical School (JATS), 1963, cited by Tadesse et al., 2008).

Postharvest losses occur at different points (harvesting, drying, threshing, winnowing, transportation, and storage) (Harris and Lindblad, 1978). Since food travels along the value chain from harvest to consumption, losses occur at each stage along the chain and contribute to total postharvest loss.

Globally, there is a dearth of data on PHLs. Estimates vary widely, and there is no consensus on the proportion of food produced that is currently lost (Adegbola et al., 2012). In Ethiopia, there are no reliable and consistent national estimates of PHLs along the value chain. The total PHL for grains was estimated to be 10 to 20% (FAO, 1977 cited in Alemu, 2016), 11 to 19% (Bedada, 2000), and 30 to 50% based on farmers own estimates (Tadesse and Regassa, 2013), which implies the grain total PHLs to ranges from 10 to 50% at the national level. Oftentimes, official reports estimate a 5–25% postharvest loss, while unofficial reports elevate it to 20–30% and at times as high as 50%.

A review of subsequent data generated on PHL figures shows high variations in numbers quoted by different experts in different organizations over time. There is no national figure for postharvest loss that is based on well-established standard methodology and national coverage (Tadesse et al., 2008). The figures commonly cited at national level are from studies that had limited area coverage and were based on rapid appraisal approaches, aggregated over storage systems and crops, etc. Most of the documented studies on grain PHL assessment focused only on a specific part of the supply chain (i.e., storage); therefore, PHL figures may not be representative of the entire FSC, and estimates were obtained by subjective estimates (surveys/interviews) and not direct measurements. Subjective estimates may not be true representative figures of losses because there is possibility of either over- or underestimations (Parfitt et al., 2010). Therefore, there is need to establish an accurate or near accurate PHLs estimation procedures for FSCs. Similarly, Alemu (2016) reported that the need to have information about pre- and postharvest grain losses was recognized by the government and there was a plan to have national pre- and postharvest grain loss surveys every five years. The first survey was planned to start in the 2005/06 production season. However, due to the difficulties in the methodology, the survey was not undertaken. There is a plan to undertake these surveys regularly in the future, once feasible assessment methods are agreed.

As has been indicated above, relative to the other stages, losses in farm stores are better addressed, though the method of assessment and whether some of the figures refer to the amount of damage, the total amount of grain lost, or a reduction in grain quality is not always clear (Tadesse et al., 2008). Published and unpublished sources of these losses reported until 2005/6 have been reviewed and published by Tadesse et al. (2008).

Based on the figures reported using a standard methodology, specifically the count and weigh method (C&W), losses due to insect pests of maize stored for periods ranging from 3 to 12 months ranged between 1 and 29.8% in the different parts of Ethiopia (except one report from Tigray that showed loss of over 46%). The range of loss reported for sorghum varied between 0.9 and 19.2% (loss of sorghum stored in underground pits was reported to reach 55%, but method of assessment was not mentioned); wheat 0.1–15.2%; barley 0.1–8.4%; teff 0–1.9% (method not known); and beans 0.3–5.5% (maximum of 14.0% reported, but method of assessment was not clear). In the same review, the magnitude of losses due to molds in different cereals grains (maize, sorghum, wheat, barley, and teff) was reported to range between 2 and 25%, the highest being in sorghum stored in underground pits. Loss due to mold in beans was reported to be up to 17.4%, although how losses due to grain molds were assessed was not indicated in the reports (Tadesse et al., 2008). Boxall (1998), using the C&W method, reported storage losses of maize, sorghum, wheat, barley, and beans caused by insects and grain molds to be 11.2, 8.1, 6.2, 1.5, and 19.6%, respectively.

Based on the different studies that were reported with known methodologies, Tadesse (2005) summarized the overall average loss of cereals and pulses altogether to range between 9.87 and 21.33%. The figure for cereals alone was between 7.23 and 14.43%, while that of pulses ranged between 12.51% and 28.35%. The overall grain loss figure range of about 10–21% is very close to losses reported by many authors for sub-Saharan countries (Tadesse, 2005).

Reports of losses along the value chain are not common in the earlier studies. However, some studies suggest that crop losses of 2–3%, 1–2%, 4–6%, 2–5%, and 1–3% occur in cereals during cutting, drying, threshing, winnowing, and transportation, respectively (Anon., 1993, in Tadesse et al., 2008). However, more recent studies seem to consider losses along the value chain, although all reports were based on survey data of farmers' own estimates. From a pre-feasibility survey study conducted in West Gojam Zone, Tadesse and Regassa (2013) reported losses of all cereals ranging from 2–6% during harvesting, 5–9% during drying and threshing, 2–3% during winnowing, 1–3% during transportation, and 14–33% during storage. Using the 4-S methodology that combines *screening, survey, sampling*, and *synthesis*, a more recent study was conducted in 2016 by FAO (2017, unpublished) in fourteen selected *woredas* (districts) located in four major regions (Amhara, Oromia, SNNP, and Tigray) of Ethiopia on four major grain crops: maize (South Achefer, Darimu, and Demba Goffa), sorghum (West Armachiho, Fedis, Derashe, and Alamata), wheat (Debre Elias, Gedeb Hassasa, Soro, and Ofla), and haricot bean (Tach Gayint, Adami Tulu Gido Kombolcha, and Loko Abaya). The findings showed that losses in grains differed at each of the postharvest functional stages, among crops and across growing areas. Losses were measured at harvesting, field stacking and drying, transportation, threshing and winnowing, storage, and marketing. Overall average PHLs for maize, sorghum, wheat, and haricot bean were found to be 21.4, 32.9, 18.4, and 25.2%, respectively.

Along the postharvest functions of the selected value chain, PHL of maize was estimated at 1.7, 2.4, 0.2, 0.9, 2.7, and 11.1% during harvesting, field staking, transport, drying, cob storage, threshing and grain storage, respectively. As for sorghum, PHL during harvesting, field drying, de-heading, transport, temporary field storage, threshing, transport to store, storage and marketing were found to be 8.7, 4.8, 0.3, 1.2, 0.4, 6.2, 1.3%, and negligible, respectively. In the case of wheat, PHLs were approximately 5.4, 0.9, 1.4, 4.3, 14.1%, and negligible for the harvesting, field staking, transportation, threshing, storing, and marketing functional stages of the postharvest system. PHLs of haricot bean were observed to be very high at harvesting due to shattering (9.3%), followed by storage losses (8.3%). Losses at field stacking, transportation, and threshing levels were relatively low (2.2, 1.4, 3.9%), and were negligible during marketing. Overall, losses were very high during storage: sorghum and maize showed a maximum loss of 11.3 and 11.1%, respectively as compared to haricot bean and wheat losses of 8.3 and 6.6%, respectively.

The impact of postharvest loss in the four selected grain crops was studied by FAO (2017, unpublished). The study included economic, nutritional, and environmental aspects. Overall, owing to the poor postharvest management system of the maize, sorghum, wheat, and haricot bean, it was estimated, based on CSA (2015) production data, that Ethiopia has lost approximately United States dollars (USD) 840.80 million, lost 11.5 billion kilocalories of nutrients, and wasted almost 1.42 million hectares of land that could have been used for production of crops. Moreover, the costs of fertilizers, improved seeds, water, and other agro-chemicals used are opportunity costs forgone! (FAO, 2017, unpublished).

Dessalegn et al. (2017) studied 14 top wheat-producing areas in three agro-ecologies (lowland, intermediate, and highland) of four regions (Amhara, Oromia, SNNP, Tigray) using a semi-structured questionnaire survey in 2014. They reported losses in wheat along the different postharvest operations (harvesting (6.8–16.3%), threshing (3.5%), cleaning (2.1%), bagging (0.2%), transport from farm to store (1.1%) and store to market (0.2%), farm storage (2.7%), etc.) to be between 14 and 23%, the average being 17%. A higher loss figure was reported when there was rain at harvest.

From studies conducted in 2015/16, FAO (2016) reported losses in maize and teff along the value chain and the associated factors that caused the losses at the different stages. The highest loss of 6.9% in maize was reported to occur during storage, followed by 2.8% during stacking; for teff, higher losses reported were during harvesting (5.6%), stacking (6.28%), and threshing (7.68%); the figure for teff storage loss was 3.2% (FAO, 2016).

Amentae et al. (2016) evaluated the supply chain management practices and losses in food value chains of teff in Becho and Dawo Districts of central Ethiopia. The study identified major chain actors and losses at each stage of the food supply chains. In the teff chain, estimated losses reported were about 8.2%, 1.7%, 2.9%, and 3.6% at the producer, wholesaler, retailer, and catering institution/consumer stages, respectively. Teff losses at farmer stage were the single highest losses for teff in the chain, indicating this as the loss hotspot for teff in the study area. Teff losses at farm level were mainly caused by problems during harvesting, threshing, and transportation from harvesting site to home. Threshing was the severest problem identified as regards losses.

Regarding haricot bean, FAO (2013a) reported losses along the value chain in three regions (Amhara, Oromia, and SNNP) of Ethiopia. The overall loss in the three regions from harvesting to consumption was reported to be 13.4%. The loss estimates for the respective regions were 19.4% in Amhara, 8.04% in Oromia, and 14.8% in SNNP across the different postharvest operations. The overall losses in haricot bean during harvesting, stacking, threshing, transport, storage, and household processing were 4.3, 2.0, 3.0, 1.2, 2.2, and 1.8%, respectively (FAO, 2013a). It was indicated that the average loss estimates at farm level were used to estimate the aggregated loss of haricot bean grain at regional level. In all regions, the grain loss at the harvesting stage accounted for the largest portion of the total bean loss. Moreover, threshing and stacking in Amhara, storage and threshing in Oromia, and storage and stacking in SNNP Regions were stages where a sizeable amount of bean losses occurred in the postharvest operation chain. Based on the CSA production estimate of the 2012/13 main season, the overall PHL in Amhara, Oromia, and SNNP Regions was calculated to be 15.7, 7.8, and 13.9% respectively (FAO, 2013a).

Studies by FAO (2013b) on losses of maize along the postharvest operations (harvesting, stacking, threshing, transport, and storage) in Amhara, Oromia, and SNNP were 8.5, 11.0, and 5.5%, respectively. When considering the different postharvest operations, losses during harvesting, stacking, threshing, transport, storage, and consumption were 2.4, 1.9, 1.0, 0.3, 1.8, and 0.9%, respectively (FAO, 2013b). The figures on loss of maize at the national level along the different postharvest operations (harvesting, stacking, threshing/shelling, transport, storage, and household processing) were 2.7, 2.1, 1.3, 0.2, 2.6, and 0.7%, respectively. The overall loss appeared to be 9.6% (FAO, 2013b).

Other studies in Amhara, Oromia, SNNP, and Tigray on sorghum indicated that losses along the postharvest operations were estimated to be 5.46, 4.97, 16.1, and 7.03%, respectively. The highest was in SNNPR compared with other regions. The mean losses of sorghum during harvesting, stacking, threshing, winnowing, storage, and processing over the regions were 2.2, 1.1, 2, 0.5, 1.1, and 2%, respectively. The overall average loss was 8.4% (FAO, 2013c).

FAO (2013d; e) collected field data from 14 *woredas* distributed among the four regions, namely Tigray (2), Amhara (4), Oromia (4), and SNNPR (4) in 2013 using farmer interviews and C&W for sample grain. Loss figures obtained by "counting and weighing" of sample grains were used only to compare with farmers' estimates on "storage losses." The results were not, thus, considered in the estimation to avoid double counting. Losses at major postharvest chain operations were estimated for each crop, both at regional and national levels. Results of the assessment indicated that average grain losses incurred during postharvest operations (harvesting, stacking, threshing, transporting, storing, and household processing) are estimated at 9.6% (maize), 6.2% (sorghum), 9.5% (wheat), and 13.7% (haricot bean) of the potential production. Total computed losses (at national level) from the 2012/13 main season production were 607,000, 231,000, 282,000, and 71,000 metric tons (MTs) of maize, sorghum, wheat, and haricot bean, respectively. The losses add up to 1,190,000 MTs. This is over 119% of the total cereals the country annually imported over the last five years on average. Converted into monetary values, the aggregate annual loss for the four crops amount to over Ethiopian birr (ETB) 10.35 billion (USD 545 million). Among the postharvest operations, highest loss occurred during harvesting of maize (2.7%), sorghum (2.2%), and haricot bean (4.3%), while for wheat highest loss (3.3%) was during storage.

FAO (2013d; e) indicated that the major causative factors of the PHLs that Ethiopian smallholder farmers can improve with some support are: lack of farmers' awareness; use of traditional farming postharvest techniques; lack of appropriate storage structures; insect/pest infestation; damage by rodents and field pests; poor drying techniques; and unexpected rain. On the other hand, causative factors over which smallholders have no control are: lack of suitable PHL management technologies; lack of quality-rewarding market system; poor technical support; and inadequate government support.

Hengsdijk and de Boer (2017) conducted a survey in all rural parts of Ethiopia (290 rural and 43 small towns), except the non-sedentary population of three zones of Afar and six zones of Somali regions. They analyzed national survey data of Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) of the World Bank for Ethiopia (2011/2012 data) and reported that farmers' own estimated loss is 24% of all cereals (maize, sorghum, wheat, barley, teff) caused by insects, grain mold, rodents, and other causes. Adoption of improved storage methods was limited, and most cereals were stored inside the house in bags (46%), followed by traditional *gotera*. Average losses were reported to be higher (27%) for wheat and lower (21%) for teff, maize (24%), and sorghum and barley (23% each.) The average PHL due to other factors was highest at 35%.

In a survey conducted in 2003, Mendesil et al. (2007) interviewed 138 farmers in Jimma area using a questionnaire survey and reported sorghum loss of up to 50% due to insects and lack of storage hygiene.

Dubale et al. (2012) carried out a survey in Jimma Zone in two agro-ecologies (low and intermediate) in 2010, of two traditional storage containers (*gombisa*, i.e., unplastered *gotera*, and polypropylene sacks) for six months of maize storage. The germination capacity of kernels obtained from *gombisa* further reduced from the initial 98 to 68.50% in six months, while that of grain stored in the sack remained non-significantly different (97.5 to 80.5%). A loss range of 10–12% was reported; insect damage increased from 2.4 to 20.8% and 2.3 to 20.1% in *gombisa* and sacks, respectively.

Sori and Ayana (2012) studied major pests of stored maize, the grain damage they cause, and associated losses in Jimma Zone, Oromia Regional State. Fifty farm stores were assessed. The study was conducted in Yebu, Asendabo, Seka, Dedo, and Kersa, the major maize-growing areas of Jimma Zone. Grain samples were separated into damaged and undamaged, weighed, numbers counted, and percentage weight losses determined using the C&W average grain damage of 64.5%. Losses of 41 to 80% were common in the store within three to six months after storage.

Minten et al. (2016) estimated that postharvest losses in the most prevalent pathway in the rural-urban value chain amount to between 2.2 and 3.3% of total harvested quantities of teff. The variation in this figure depends on the storage facilities used and on assumed losses during transport at the farm. These losses are significantly lower than is commonly assumed for staple foods, possibly because of the rather good storage characteristics of teff due to its low moisture content. These findings, nonetheless, point to the need to gather further solid evidence on postharvest losses in staple foods in these settings to ensure appropriate policies and investments.

Based on farmers' own estimates, Bachewe et al. (2017) reported crop losses during storage averaged: 5% in teff and sorghum; 6% in barley and maize; and 7% in wheat and pulses. Losses during storage were estimated at between 5 and 7% of stored output.

Bachewe et al. (2018) found that farmers' self-reported storage losses amount to an average of 4% of all grain stored and 2% of the total harvest. These storage losses are shown to differ significantly by socioeconomic variables and wealth, but also by crop and humidity. We further see strong spatial heterogeneity in storage losses, losses being significantly higher in the southwestern part of the country. Efforts to scale up the adoption of improved storage technologies to reduce storage losses at the farm level should take into consideration these characteristics.

Ashagari (2000) estimates suggest that the magnitude of maize postharvest losses in Ethiopia is tremendous, ranging from 5% to 26%.

Beyene and Ayalew (2015) reported harvesting, drying, threshing, cleaning, transport, storage, etc. losses of maize in four regions (Amhara, Oromia, SNNP, and Tigray) to be about 1.1, 0.4, 0.8, 0.3, 0.2, and 1.7% respectively. Losses at the different postharvest operations in Amhara, Oromia, SNNP, and Tigray were about 6.1, 4.6, 6.5, and 1.2%, respectively. However, these estimates were based on farmers' responses; no measured data were available.

Chichaybelu et al. (2015) reported an average pre-storage loss of 8.9% in chickpea, the least loss of 5.6% from Oromia and the highest loss of 12.1% from Tigray Region. Mean loss of 3.0% was recorded during and after storage. The least loss during and after storage (2.2%) was also recorded from Oromia, while the highest loss (8.2%) was from Tigray Region. In general, respondent farmers suffered an average PHL of 11.8% from the 2013/14 chickpea harvest, ranging from as low as 7.8% to as high as 20.3% in Oromia and Tigray Regions, respectively.

FAO (2016) conducted field studies on teff in Workima *kebele* in Machakel *woreda* in Amhara Region, and on maize in Burka Golu *kebele* in Deder *woreda*, Oromia Region. The primary data sources were smallholder farmers randomly selected from the study *kebeles*, farmers' service cooperative associations (unions), and traders at different levels ranging from farmer traders to regional-level wholesalers. Secondary data were collected from various reports and documents. According to FAO (2016), in teff the highest mean loss was recorded in wholesaling (8.5%), followed by threshing (7.7%). The average estimate of grain losses during stacking/piling, harvesting, and storage were 6.3, 5.6, and 3.2%, respectively. Thus, the cumulative PHL was estimated to be 24.9%, without considering the quality losses.

AGRA (2014) estimated PHL of crops in Ethiopia to be between 10 and 50%, loss for individual crops being maize 17.4%, rice 11.9%, sorghum 12.5%, and millet 11%. On the other hand, AGRA (2014) made benchmark estimates of PHL along the value chains of maize, millet, sorghum, groundnut, cowpea, and haricot bean as 9.5, 13.2, 13.2, 7.7, 5.5, and 5.5%, respectively. The perception of PHL for these crops by the different actors also shows that estimates by researchers and extension workers tend to be higher than what is perceived by other actors operating in the same value chain.

3.4 Comments on available PHL assessment studies

The reviews of Tadesse et al. (2008) show that in Ethiopia efforts to assess grain losses that occurred in farm stores have been made since the 1970s. Some of the loss figures frequently quoted are decades old (e.g., FAO, 1977 cited in Alemu, 2016). The reliability of some of these figures is questioned, since the methodologies used to estimate them are not mentioned and the conditions under which these losses were estimated are not given (Tadesse et al., 2008), some loss figures are aggregated over agro-ecologies and/or over different crops types, storage systems, etc., and the magnitude of loss inflicted in each ecology and/or crop is not known (Boxall, 1986). Some loss figures are either questionnaire data based on farmers' estimates (mostly exaggerated and sometimes underestimated) or are a guess estimate, rather than measured data. With some figures, it is difficult to tell whether they are referring to percentage gain damage or weight loss. Moreover, Hodges (2013) indicated that early studies on storage losses often did not take into account the grain that was removed from stores during the storage season as a result of household consumption, marketing, etc. But these removals are important because each lot of grain removed will have its own degree of loss, i.e., not the same loss as the grain that remains in the store for the whole season. Boxall (1998) indicated that PHLs should be estimated based on losses at each stage of the postharvest system and assuming that each loss found is a percentage of the amount remaining from the previous stage. Otherwise, if losses are determined on the basis of the original weight of the crop, it can lead to an overestimation of losses.

Most the estimates refer to storage losses, and information on losses in other components of the postharvest system is very limited. Little data on harvesting, drying, or transport losses are reported; most are derived from questionnaire surveys or are just guess estimates. The best-quality data are considered to be measured estimates using standard methods. Methods such as questionnaire surveys or guess estimates would generally be less reliable, although the measured estimates may not be much better than other approaches when they are being applied to much wider circumstances than those for which they are derived.

Most postharvest surveys that studied storage pests generally followed stratified sampling in which individual farmers (for group or individual interviews and/or for providing grain samples) were identified from selected peasant associations in pre-determined *woredas*. Certain surveys attempted to categorize sampling sites based on altitude or agro-ecologies: *Dega* (cool zone), *Woina dega* (subtropical zone), and *Kolla* (tropical zone).

It is worth noting that the majority of postharvest studies in Ethiopia are focused on maize, sorghum, and wheat in that order. The least attention has been given to haricot bean, teff, and barley in decreasing order. Therefore, data pertaining to type, extent, and causes of PHLs are almost nonexistent for crops like barley.

Tyler (1982) reported that postharvest losses may be due to a variety of factors, the importance of which varies from commodity to commodity, from season to season, and to the enormous variety of circumstances under which commodities are grown, harvested, stored, processed, and marketed. It is therefore important not only to work with figures that are good estimates at the time and in the situation they are taken but also to be aware that at other times and in other situations the figures will differ. This necessitates regular recalculation of loss estimates with the best figures available, a task addressed by the new African Postharvest Loss Information System (APHLIS).

Loss assessment results are very much location specific, technology and practice dependent, and based on sample statistics (Guisse, 2010). Unless the field conditions or processing plant machinery type and condition are given, losses from different studies, studies made in different locations, or studies done under different conditions cannot be compared. The usefulness of loss assessment studies is to make people aware of the need to allocate resources to post-production research and to identify priority areas for research (Guisse, 2010).

3.5 Review of development interventions on postharvest loss management

Reduction of postharvest losses requires an appropriate intervention through the well-coordinated effort of many governmental and non-governmental institutions. Oftentimes interventions are very fragmented and redundant, as a result of which scarce resources are wasted and no synergies are observed. Interventions in the area of postharvest management could be assessed from education, research, extension, and development perspectives. In this context, several institutions have been engaged in postharvest-related issues in view of achieving postharvest loss reduction. However, there is hardly any comprehensive database to refer to in order to know who is working on what and to capitalize on best practices achieved through the implementation of the respective intervention projects in the country. Therefore, the purpose of this document is to throw some light on past and present interventions by different institutions and capitalize on positive impacts achieved for potential future scale-up. There are ongoing efforts in Ethiopia to boost postharvest management.

3.5.1. Postharvest research strategy

National postharvest research strategy has been prepared by EIAR in collaboration with different higher learning institutions, though the effort requires further improvements. Accordingly, federal and regional research centers are considering postharvest and food science as one of the focus areas of research.

3.5.2. Postharvest management strategy for grain crops

The Postharvest Management Strategy of Grains document was developed and validated in alignment with the provisions of the Rural Development Policy and Strategies of April 2003 and the Growth and Transformation Plan (GTP) II (2015–2020) (MoANR, 2018). It has been accepted as a working document, and the suggested implementation priorities will be owned and managed by the Agricultural Mechanization Directorate of Ministry of Agriculture and Natural Resources (MoANR) and Regional Bureaus of Agriculture (RBoAs).

3.5.3. Establishment of postharvest platform in Ethiopia

A postharvest platform was established on January 2, 2016 under the auspices of MoANR. This platform consists of relevant stakeholders who meet biennially to discuss postharvest issues and support the government in the implementation of postharvest reduction interventions.

3.5.4. Postharvest extension

In alignment with the Malabo Declaration of the African Head of States in 2014 regarding reduction of postharvest losses by half by 2030, the government of Ethiopian has launched a national grain postharvest management strategy to reduce postharvest losses of agricultural produce to 5% by 2020. The 5-year strategy by the MoANR is meant to reduce postharvest losses from between 15% and 20% to 5%. The strategy will reduce losses through the adoption of systematic and structured mechanisms. The strategy is to limit food losses throughout the agricultural value chain through the adoption of appropriate technologies, storage, and management systems. The improvement of market access and efficiency, access to agricultural financing, and the promotion of value addition are also key focus areas.

Although there is no separate extension unit assigned for postharvest management like that of pre-harvest aspects of crop production, there is a growing effort being made by the Ministry of Agriculture and Livestock Resources (MoALR) to prepare and deploy various postharvest manuals. Manuals for postharvest management of grain and horticultural crops were prepared with the help of FAO, and both are going to be translated into the major languages of Ethiopia. Moreover, FAO, together with Jimma University and MoALR, provided customized trainings for trainers and farmers on different aspects of grain PHM.

3.5.5. Agricultural mechanization forum and national agricultural mechanization sector strategy

The MoANR developed a national agricultural mechanization sector strategy through a series of strategic, systematic, and stakeholder consultation processes in 2013. An agricultural mechanization forum was also established in 2016 under the auspices of MoALR, Rural Development and Food Security (RED&FS) structure, Agricultural Technical Committee (AGTC)-Agricultural Research and Technology (ART) Task Force. The objective of the forum is to support the modernization of Ethiopian agriculture and the livestock sector, with a view to enhancing the livelihoods of smallholder farmers and pastoralists.

Specific objectives of the forum are:

- To assess: the national knowledge base in agricultural mechanization; constraints to and demand for access to mechanization; issues with the supply of financial services for agricultural machinery; and lessons from within and outside the country;

- To assess the need for further refinement in the mechanization strategies of the then-MoANR, Ministry of Livestock and Fisheries (MoLF), and EIAR;

- To bring stakeholders along the mechanization value chain (financing, production, distribution, and utilization) together to discuss these issues and strategies and build a consensus on the way forward.

3.5.6. Postharvest education in Ethiopia

Currently, there are about 45 higher learning institutions (HLIs) in Ethiopia, of which about 20 support the agriculture sector in several areas and cultivate talent to work within the National Agricultural Research System (NARS), conduct agricultural research, and promote generated technologies. For the first time in Ethiopia, a training program in postharvest management *per se* was inaugurated in 2008 at Jimma University. Currently, the University provides training at BSc, MSc, and PhD levels in postharvest management and related programs. Moreover, there are universities that are offering trainings at BSc, MSc, and PhD level in the areas of food science and postharvest technology, food science and nutrition, food engineering, food technology, and bio-resource engineering. There are no private universities or colleges that are currently offering trainings in postharvest management.

Worth mentioning is the absence of agricultural technical and vocational education and training colleges (TVETs) that can provide customized training on postharvest management to development agents (DAs), farmers, women, and rural youth, with the exception of the recently launched technical and vocational education training program for combine harvester operators at Agarfa. This being an important effort to be further cultivated, it is critical and timely to have trainings at TVETs for rural and urban youth in different competency units of postharvest management.

3.5.7. Professional societies

Plant Protection Society of Ethiopia (PPSE)

PPSE is a society formed by plant/crop protection professionals in the country and is licensed and registered by the Charities and Societies Agency of the Ministry of Justice. The society was established in 1992 by the merger of two previously formed committees: the Ethiopian Phyto-pathological Committee (EPC), established in 1976, and the Committee of Ethiopian Entomologists (CEE), established in 1981. The objective of PPSE is to contribute towards the development of Ethiopian agriculture by reducing crop losses caused by pests through promoting effective research, documenting and disseminating of scientific information, encouraging professional growth, and fostering interdisciplinary interaction among plant protection scientists to solve problems related to plant protection.

The society has been conducting research in the area of plant/crop protection. Many of the storage studies were conducted by members of the society. A very good account of this has been depicted in its recent twenty-second annual conference held with the theme of "Post-harvest pest management research, education and extension in Ethiopia: The status and prospects."

Ethiopian Society of Postharvest Management (ESPHM)

ESPHM is non-profit professional society established under Charities and Societies Proclamation number 621/2001 article 68 (1). It was registered as an Ethiopian society on June 9, 2016, with the main aim of creating a forum/platform for members to jointly discuss, improve, and share information and experiences. In addition, the society will provide support and collaborate with higher learning institutions and colleges to share experiences. Last but not least, it aims to enhance the capacity of postharvest-related professionals through strong networking with professional societies that have similar objectives. The society successfully held its inaugural international postharvest conference on the February 26–27, 2018 in Addis Ababa.

3.5.8. Engagement of NGOs and private institutions in promoting postharvest technologies

Promotion of hermetic/improved storage structures

Many NGOs and international organizations, including SG 2000, FAO, Gesellschaft für Internationale Zusammensarbeit GmBH (GIZ), Feed the Future (FtF), ACDI/VOCA, and Mercy Corps have been involved in promoting postharvest technologies, with particular emphasis given to storage structures and crop threshers. There is reported success in both cases.

SG 2000 is also promoting the use of hermetic metal silos and triple-layer Perdue Improved Crop Storage (PICS) bags for storage of grains. PICS bags are relatively cheap and can be used for at least three seasons. Hermetic metal silos are relatively costly; however, they can be used for more than 15 years and thus can offset the initial relatively high price. However, the adoption of these storage structures is just picking up. Provided that the government of Ethiopia designs a special scheme to bring down the cost of galvanized metal sheeting, which accounts for almost 90% of the total cost, then it will be possible to distribute the technology throughout the country.

Local artisans trained in manufacturing of postharvest technologies

Melkassa Agricultural Research Center (MARC), through the FAO postharvest loss reduction project, has trained a number of artisans from four regions (Amhara, Oromia, SNNP, and Tigray) on construction, use, and maintenance of metal silos. Following the training, artisans were supported to fabricate metal silos to sell to local farmers at subsidized rates. Selam Technical and Vocational Center (STVC) has been actively involved in the fabrication of different types of postharvest technologies, including multi-crop threshers, driers, churners, etc.

Involvement of the private sector in adoption/ generation and promotion of postharvest technology

Experiences from many developed countries as well as developing countries in Africa and Asia clearly show that without the active involvement of the private sector, sound postharvest systems cannot be achieved. To date, the involvement of the private sector in Ethiopia in adoption/ generation and promotion of postharvest technologies is very limited. However, there are good practices that deserve mention.

It is long established that wheat producers in Arsi area (e.g., Gedeb Hassasa) in Oromia Region use combiners for harvesting and threshing of their crops. This service has been provided by the private sector for many years. Now the same technology is moving to Amhara Region, particularly to Debre Elias area, to harvest and thresh wheat. In general, the effort is very encouraging and needs to be scaled up. However, it is very important that drivers of those combiners are very well trained in not only driving but also in appropriately adjusting and operating the machines. Based on an earlier assessment, regular assessment of those machines for fitness to serve the purpose and that of the driver for their attitudes is recommended.

Service providers in Zewai and Meki area in Oromia Region have been assisting farmers in providing a rental threshing service for maize and wheat at a reasonable price. These service providers move their multi-crop threshers from area to area. Therefore, in addition to expanding infrastructures, the design and development of handy, portable, and yet efficient multi-crop threshers would be essential.

Shai Shone, the local distributer for **PICS** (which are triple-layer sacks), has doing an amazing job in promoting and distributing the technology to several areas in Ethiopia, including remote and less accessible locations. It has several local distributor agents through whom information is delivered to traders and users of PICS pertaining to proper use of the technology. Currently, preparations are underway to produce the bag in Ethiopia and scale up and out its distribution.

Distributors of ***GrainPro Super Bags*** have been in operation in Ethiopia for several years. These bags come in different sizes, and some unions in Oromia and Sidamo have started using the 25- ton capacity Grainpro SuperGrain bags. However, their distribution is very limited, unlike the PICS sacks.

3.6 Management options for reduction of PHLs

Details of the available options for the reduction of storage losses can be found in Tadesse et al. (2008) and WFP (2012). The following measures are extracted from these and other relevant sources. These include traditional grain management practices of farmers and research recommendations on harvesting and pre-storage measures, improvement of storage structures, and use of physical methods, inert materials, botanicals, biological control, resistant varieties, chemical control, and integrated pest management (IPM).

3.6.1 Traditional grain management practices of farmers

Tadesse et al. (2008), Tadesse and Regassa (2013), and FAO (2017) reported that, in an effort of reducing storage losses, farmers are exercising numerous traditional practices such as use of plant materials, admixing with ash, mixing with teff or finger millet, and warming grain. The plant materials repeatedly mentioned were *Kinchib, Erret, Merez, Ye-azo qitel, Croton macrostachys*, and eucalyptus leaves. According to the list of the Ethiopian names of plants, *Kinchib* refers to different plants—*Euphorbia tirucalli* is one. The others are *Senecio longiflora* and *Pterolobium stellatum*; all are in different families of plants. *Merenz* is *Strychnos innocua* in the literature. *Erret* is Aloe vera. *Ye-azo qitel* is not in the list, but *Azo hareg* is *Clematis simensis*. Postharvest protection measures commonly practiced by farmers in Ethiopia are listed in Appendix Table 1.

Regardless of the rich experience of farmers in using different indigenous ways of protecting the grains in the store, there is a tendency towards the use of chemical control measures such as malathion, Actellic, and DDT dusts or Phostoxin tablets to treat grains meant for market before storage. The reason for the use of chemicals is that they are fast in acting against storage pests. However, at times such chemicals may become ineffective due to mishandling problems, inappropriate dosage, and impurity of the active ingredients. In addition, there are health hazards associated with their use. Some farmers reported that women and children are experiencing fatalities due to suicide by ingesting phosphine tablets meant for storage pest control.

3.6.2 Research recommendations

Harvesting and pre-storage measures

It is always recommended to make all the necessary preparations before the new harvest. This should be followed with careful and timely harvesting. Some of the major storage insect pests start the infestation in the field. Field infestation is a problem, particularly when the field is located close to infestation sources such as granaries and when the same crop is grown in the same field year after year (mono-cropping). In addition, delayed harvesting can cause field infestation. Field-infested crops deteriorate shortly after storage. Therefore, field isolation from infestation sources, crop rotation, and prompt harvesting are important measures for the reduction of losses in the subsequent stages of the postharvest system. Moreover, selection of non-infested/uninfected grain for storage, proper drying to the recommended moisture level before storage, removal of all residues, appropriate construction, repair of storage structures, and implementation of hygiene measures are some of the cultural practices recommended. Compton et al. (1993) also indicated that storage losses caused by insects and rodents can potentially be reduced by simple hygienic measures such as cleaning stores and destroying infested crop residues. Since measures taken by individual farmers may have little impact, a community campaign may be needed in some cases.

Labor constraints and unpredictable weather often force farmers to harvest at a non-ideal time. To address these problems, various types of equipment are available to speed up harvesting and threshing/shelling. The World Bank (2011) indicated that there are no data showing any difference in PHL between hand and mechanical harvesting for sub-Sahara Africa. In principle, hand harvesting is likely to be less wasteful, but labor constraints can lead to delays in or failures to harvest, which can result in significant postharvest losses. On the other hand, others argue that the traditional method of harvesting using sickle exposes the grain to shattering loss. In addition, mechanical harvesting as opposed to manual harvesting results in a high percentage of broken grains, especially where poor calibration of the machine is done.

Threshing should be done when the harvest is adequately dried since damp crops will not be threshed well. During threshing, cracking and breaking the grain should be avoided since such grain is susceptible to pests during storage. There are different machines that can provide timely and efficient threshing/shelling when appropriately calibrated. Threshers/shellers can be owned by a group of farmers or can be rented from private service providers.

Drying grain is the most important measure available to all farmers. Great care must be taken to ensure that grain to be stored is dried to safe moisture content before it is put into store. If this is not done, grain heating and spoilage due to molds may ruin the entire crop. Furthermore, insects proliferate quickly in grain that is not well dried; and insecticides are less effective on moist grain.

Cribs (dual-purpose drying and storage structure with open sides to allow extensive airflow) have been promoted, particularly for maize. In addition to reducing losses in maize harvested during the wet season, cribs may permit farmers to harvest earlier. However, many of these cribs are expensive in materials and labor, and uptake by farmers has been sparse. Farmers in Enebse Sar Midir *woreda* indicated that the ventilation opening (wire mesh) in the improved *gotera* demonstrated to them at farmers' training centers (FTCs) allowed birds to access the grain. This was mentioned as one of the reasons that farmers refused to adopt the improved *gotera* (Tadesse and Regassa, 2013).

Improved/ modified storage structures

The main purpose of any crop storage structure is to protect grain from deterioration caused by rain and ground moisture and to provide a barrier against attack by insects and vertebrate pests. However, most traditional storage containers used by farmers in Ethiopia are extremely poor in construction and maintenance, and they appear to be one of the major causes of storage losses (Tadesse, 1991; 2003 and Tadesse et al., 2008). Hence, one of the main approaches to reduce PHL during storage is to change these conditions. This can be done either by modifying existing store types so that they perform better or by introducing improved types from elsewhere. However, not only the cost but also social acceptability of the modification/improvement should be considered for successful adoption by farmers.

Different modified/improved storage structures were recommended and promoted by a number of institutions in Ethiopia. SG 2000 had started to promote improved stores in 1995 in several parts of the country, which was later taken over by the then-Ministry of Agriculture and Rural Development (MoARD) (Anon., 1996 cited in Tadesse et al., 2008). The Freedom from Hunger Campaign of the early 1970s recommended crib-style grain stores with rat baffles, which were constructed on demonstration sites throughout the country (UNDP/FAO, 1982). Recently, the Amhara Bureau of Agriculture tried to demonstrate improved/modified storage structures at different FTCs in the region. The modifications were: raising the store well above the ground; strengthening the base with cement; introducing rat guards; and spouts for loading and unloading (through discharge spout at the base) grain. Regarding underground pits, different improvements have been recommended since early days (Gilman, 1968; IAR, 1973; Boxall, 1974; Lynch et al., 1986; Mekonnen et al., 1997; Dejene, 2004). Compton et al. (1993) also indicated that although farmers are normally willing to experiment with new construction methods, it is obvious that a farmer will rarely build a new store until the old one needs to be replaced. Thus, grain storage projects with a short lifespan may see little progress in the uptake of construction recommendations over the project lifetime. Even when an improved store has clear technical and economic advantages, many farmers may still be unable to adopt it. Institutions and projects promoting improved stores may need to address issues of production, distribution, and provision of credit (Compton et al., 1993).

Several studies have shown that metal silos demonstrated the best efficacy over other storage methods (super grain bags, inside polypropylene bags, etc.) and if adopted could reduce the negative impact of larger grain borer and other storage pests that cause postharvest losses among small-scale farmers. Gitonga et al. (2013) indicated that the use of metal silos prevented damage by larger grain borer and maize weevil for 98% and 94% of adopters, respectively. This study finds evidence that metal silo technology is effective against the main maize storage pests. Its adoption can significantly improve food security in rural households. Metal silos can be fabricated in different sizes, from 100 kg to 3,000 kg holding capacity, by trained local artisans, with the corresponding prices of USD 35 to USD 375 (Tefera et al., 2011). With appropriate training of local artisans, FAO has managed to produce metal silos with a capacity of 10 tons for ETB 4,500. The use of metal silos, therefore, should be encouraged in order to prevent storage losses and enhance food security in developing countries. As the initial cost of metal silos is high, policies to increase access to credit, to reduce the cost of sheet metal, and to promote collective action can improve their uptake by smallholder farmers (Gitonga et al., 2013).

High-density polyethylene (HDP) containers (drums and jerry cans): The most common locally available containers include drums and recycled vegetable oil containers. Twenty-liter vegetable oil containers are quite popular in villages throughout Africa. Under proper closure and sealing, they are typically used to store small volumes of seeds with the required hermetic condition.

The use of PICS bags, developed by a team at Purdue University, is being promoted in Africa with funds from the Gates Foundation. Their use has been promoted in Ethiopia by SG 2000 and private investors. It is a storage technology. PICS technology uses plastic bags to achieve hermetic storage of cowpeas and other seeds. Threshed grain dried to an appropriate moisture level and free of crop debris is placed into 50- or 100-kg capacity high-density polyethylene bags with 80-µm (micrometers) thickness. PICS sacks are composed of two high-density polyethylene plastic liners and a printed woven polypropylene bag for reinforcement. A first bag is completely filled with grain, but with a 20 to 30 cm neck, which is tied securely. Then, this bag is placed inside a second bag, the neck of which is ultimately to be tied securely. Finally, these two bags are placed inside a third woven polypropylene bag used for its strength. With the third bag tied securely, the container can be handled without bursting the inner bags.

GrainPro Superbags, also called the SuperGrain bag[IIITM], is a type suitable for use by small-scale farmers and traders to store seeds in their home or store. It has a very minimum transmission capacity for oxygen and moisture. It is available with capacities of 100 kg. Seed is placed in 78-µm multilayer polyethylene bag with a proprietary barrier layer that makes its permeability to oxygen far lower than polyethylene alone. It may use a two-track zipper and is sealed using a zipper slider. The sealed bag is then placed in a protective woven outer bag. With careful use, the bag will last for about five cycles, and small punctures can be repaired with tape. Some cooperatives in Ethiopia have started to use large-size cocoons (up to 25 tons) for storage of grains.

Admixing grain with inert dusts or small seeded grains
Mixing grain with inert dusts, such as SilicoSec, Melkabam (filter cake), and wood ash (Tadesse et al., 2008; Demissie et al., 2008a), and with teff or finger millet can control storage pests effectively and extend the period of storage (Tadesse, 2003; Tadesse et al., 2008). SilicoSec is a very effective diatomaceous earth (DE) registered in Germany. Many DE dusts are now available commercially and are registered for use as grain protectants in Europe, the United States, Australia, China, Japan, and the Middle East. Research has demonstrated that DEs are effective and environmentally friendly grain storage protectants and have good potential to substitute for chemical insecticides, deserving further investment in their research and promotion in Ethiopia.

Treatment with botanicals
Mixing a local plant or plant powder with grain is a common practice of traditional farmers in Ethiopia. Several attempts have been made to evaluate different botanicals as grain protectants under natural and artificial infestations in the laboratory and storehouse.

Plant powders: Powders of some plants/seeds were found to be effective in controlling insect pest in storage. These include neem seed powder, *Chenopodium* plant powder, *Pyrethrum* flower powder, and many others (Tadesse et al., 2008; Demissie et al., 2008b).

Vegetable oils: Different vegetable oils were evaluated and recommended for use against some major pests of stored grains. Higher rates (5–10 ml/kg) are required for more effective results. However, oil treatment can reduce seed germination (unless reduced rates are used) (Tadesse, 2003; Tadesse et al., 2008; Demissie et al., 2008).

Physical control
The traditional method of warming grain on a clay pan over fire and exposure of grain to the sun were found to be effective for the control of insects on stored grain. Effectiveness was improved by spreading infested grain on a black polyethylene sheet, covering them with a sheet of translucent plastic, and weighing down the edges with stones (Tadesse, 2003; Tadesse et al., 2008).

Biological control
Tadesse (2003) reported the occurrence of predator bugs (*Xylocornis* spp.), spiders, and lizards in simulated on-farm storage facilities studied at the Bako and Nazareth agricultural centers of the EIAR. Moreover, Tadesse (1991; et al., 1996; 1997) recorded six species of wasps from farm-stored maize in Ethiopia. *Anisopteromalus calandrae* (Tadesse, 1991; 1997) and *Choetospila elegans* (Tadesse, 1991; 1997) were the most common natural enemies recorded on farm-stored maize. *A. calandrae* is a well-known cosmopolitan parasitoid of Coleopterans, and perhaps some Lepidopterans, associated with grain in storage. Similarly, *C. elegans* is a cosmopolitan parasitoid of small beetles on stored grains (Tadesse, 1991; 1997).

The presence of a considerably high number of species and individuals of each species may indicate the possibility of using predators and parasitoids in stored product insect management (Tadesse, 1991; Tadesse et al., 1993). There may be possibilities for environmental manipulation to enhance the effect of natural enemies in storage. However, a thorough knowledge of their biology and ecology is required. As has already been indicated, a major problem with biological control is its incompatibility with chemicals, since natural enemies of insects are often more susceptible to the pesticide applied than are the insect pests themselves.

Classical biological control (the introduction of a natural enemy to control an introduced pest) is being used against the larger grain borer in several African countries. The larger grain borer, which was accidentally introduced in Africa in 1970s, has now reached 20 countries, including Ethiopia. It was not recorded until 2008 in this country despite its presence in neighboring Kenya (Tadesse et al., 2008). As indicated above, a predator beetle (*Teretrius* (*Teretriosoma*) *nigrescens*) has been introduced and released for the management of LGB in some affected African countries such as Benin, Ghana, Guinea, Kenya, Malawi, Tanzania, Togo, and Zambia (Tadesse et al., 2018). In addition, many indigenous natural enemies have been recorded from farm-stored grain in Ethiopia (Tadesse, 1991; 1997; Tadesse et al., 2008), indicating the possibility of using predators and parasitoids in the management insect pests of stored grain.

Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* are known for their effectiveness against different insect pests of stored grains. Kassa et al. (2002) assessed the efficacy of 13 isolates of entomopathogenic fungi belonging to *Beauveria, Metarhizium*, or *Paecilomyces* spp. from Ethiopia against *S. zeamais* and *P. truncatus* in the laboratory. *P. truncatus* proved more susceptible to the entomopathogenic fungi tested than did *S. zeamais*. The results revealed the higher potency of *M. anisopliae* compared with the *B. bassiana* isolates tested, although a total immersion bioassay was used, so this result might have been anticipated. The study suggests that the use of entomopathogenic fungi may hold promise as an alternative method to control pests of stored products in Ethiopia.

Use of resistant varieties

Varietal resistance plays a significant role in pest management. The use of resistant cultivars can reduce the severity of an infestation. Unfortunately, traits that contribute to improved grain storage have been largely ignored by breeders until recently. Since infestation by some of the major insects start in the field, use of maize varieties with tight and complete husk cover that extends beyond the tip protects the grain better than those with bare tipped ears (Tadesse, 1991; Demissie et al., 2008).

Different authors have reported the existence of variations in maize genotypes' resistance to major storage pests such as the larger grain borer and maize weevil. Tadesse (1991) and Tadesse et al. (1994; 1995) evaluated 25 maize genotypes for resistance to the maize weevil damage in the laboratory at Bako Agricultural Research Center in 1989 and reported that maize varieties differed in their intrinsic susceptibility to maize weevil damage. Tefera et al. (2011) reported that host plant resistance can be used as a vital component of an integrated pest management strategy against larger grain borer and maize weevil. Mechanisms of resistance to the maize weevil and larger grain borer are similar. Significant differences in haricot bean varieties' resistance to insect pests in storage have been reported by many authors (Tadesse et al., 2008).

Recently, 21 maize varieties collected from Bako Agricultural Research Center, western Ethiopia were screened for resistance against the maize weevil. It was found that some were resistant, some were moderately resistant, and some others were susceptible, based on Dobie index of susceptibility and selection index (Hiruy and Getu, 2018). Hiruy and Getu (2018) mentioned that the resistant varieties could be stored relatively for longer period (≥ 2 months) under farmers' storage conditions. Hence, these resistant varieties could be used as a cheap, ecologically sound, and effective management method to reduce loss caused by maize weevil under storage conditions. Currently, one weevil-resistant maize variety has been released by the National Maize Research Center.

Chemical control

Storage pests can effectively be controlled by synthetic insecticides. However, resistance development by pests, environmental contamination, health hazards, etc. associated with their use should be minimized as much as possible. Chemical treatment includes preventive application of residual insecticides that are designed to limit the invasion and development of damaging insect infestations and remedial fumigation that provides rapid control of existing insect populations. The use of chemical insecticides in the form of sprays, fumigants, or dusts against stored grain pests have been reported by many workers, each with varying degrees of effectiveness and applicability.

Synthetic pyrethroid insecticides such as permethrin and deltamethrin that can be applied as a dilute dust insecticide can control *P. truncatus* very effectively. However, these insecticides are not so effective against other storage pests such as grain weevils and flour beetles, which are often found together. These species are more susceptible to organophosphorus insecticides. Hence, both types of insecticides can be applied in order to control the whole complex. Combinations such as pirimiphos-methyl and permethrin (Actellic Super), deltamethrin and pirimiphos-methyl, or fenitrothion and fenvalerate, or fenitrothion and deltamethrin (Shumba Super) have been used successfully to protect farm-stored grain. Farmers are advised to mix insecticide with shelled grain and use residual sprays in stores. Fumigation with phosphine is effective in large-scale stores. When using a pesticide, always wear protective clothing and follow the instructions on the product label, such as dosage, timing of application, etc. After treating with dusts and before consumption, grain must be washed to remove pesticide dust particles and then dried before processing.

There are different insecticide chemicals that can be used in storage. Insecticide dusts are easily applied, relatively free from hazard, and readily accepted by farmers because they closely resemble the traditional practice of using sand or ash with grain. Dilute dusts are the most commonly recommended formulations for use on small farms, because of their lower toxicity, simplicity of handling (no need for spraying equipment), and the ease with which they fit into many traditional storage practices. The organophosphates pirimiphos-methyl, fenitrothion, and malathion dusts are the commonly recommended insecticides. They are effective against most stored grain pests, but less effective against larger grain borer. Thus, the synthetic pyrethroids deltamethrin and permethrin are recommended to be used in a mixture with the organophosphates. There are mixed formulations such as Actellic Super. Phostoxin tablets are also effective fumigants. However, the use of fumigants in small-scale farm storage is not advised for two main reasons. First, for fumigation, airtight conditions are necessary, which cannot be achieved in an on-farm store. Second, fumigation should be done by trained personnel wearing protective closing for it can be dangerous to the applicator.

Some researchers suggested that mud plaster can be used as a seal and stores could be fumigated using high doses of phosphine, although leakage could be a problem. Other investigators who compared various mud structures concluded that none retained an effective concentration of phosphine gas for longer than a day, unless polythene sheet linings were used (Compton et al., 1993). Most farmers in the survey area appear to be unaware of the necessity for proper sealing, and about the necessity of leaving the grain sealed for an adequate amount of time.

Rodents can be controlled by rodenticides (poison baits) in addition to hygiene measures and using cats and traps around the storage area. *Gotera* with raised legs could be fitted with rat guards. In cases of severe infestations, individual efforts may not be effective because of re-infestation from the surroundings, which may require rat control campaigns.

The condition of grain in storage should be monitored frequently for timely action. The correct chemicals should be available to farmers in the appropriate packaging and size at the right time. The shelf life may be critical where the supply chain to the farmer is long or suppliers keep insecticides in less-than-ideal conditions. Misuse of chemicals by farmers appeared to be a common problem. As a common problem, different doses of tablets are applied to their grains. Moreover, farmers often fumigate their grains at the time of storage when there is no or little infestation. Some farmers also used DDT (non-recommended chemical) on their grains meant for sale. Better extension service to farmers is required to curb the problem of pesticide misuse. Pesticide retailers should also be educated, since they are important sources of information for farmers.

Integrated pest management (IPM)
The conflict between the goals of reduced pesticide usage and production of sufficient food and fiber for the ever-increasing human population provides a strong impetus for the development of the cost-effective and ecologically friendly alternatives that are major components of IPM. IPM attempts to integrate available pest control methods to achieve an economical and sustainable combination for a particular local situation. Often, emphasis is placed on the use of resistant crop varieties, biological control, cultural methods, and other non-polluting methods. In IPM, chemical pesticides are used only when necessary, especially when they can be integrated with other control methods.

The IPM concept emphasizes the integration of disciplines and control measures such as varietal resistance, cultural methods, insecticidal plants, natural enemies, and pesticides into a total management system to prevent pests from reaching damaging levels. These should be combined in an integrated pest management strategy, taking into account costs and feasibility of the control methods, because none of the various methods can ensure safe storage.

As a general observation, postharvest practices in Ethiopia are still traditional. Actors in the food supply chain do not use appropriate technologies for reasons such as lack of awareness, unavailability of technologies, limited economic status of the farmers, lack of credit service to buy technologies, etc.

4. REVIEW OF EXISTING PHL ASSESSMENT METHODS

4.1 Review of globally used postharvest loss assessment methodologies

Several loss assessment approaches can be identified, each serving a specific purpose (GSARS, 2018). These approaches should be considered more as complements than as substitutes. GSARS (2018) guidelines recommend using probability sample surveys as the backbone of any loss assessment, complemented by other methods that may be used mainly as preliminary assessments or to further analyze certain aspects related to postharvest losses.

This report is a review of relevant literature, which includes publications, manuals, methodologies, and guidelines on estimating postharvest losses of the FAO as well as publications by other institutions, international organizations, and relevant country experiences on estimating postharvest losses.

Assessments may be made by surveys (traditional or improved), designed experimental studies (field studies or trials), or more recently by using econometric modeling (special cases of machine learning algorithms).

Losses occur at all levels of the value chain, reflecting a variety of possible factors or causes. The methods and techniques used for measuring them will vary depending on the nature of the losses: whether they are caused by bio-deterioration linked to climatic conditions (humidity, temperature, rainfall, etc.), pest infestation, spillage, scattering, or other mechanical reasons, including removal by birds, rodents, etc.

A certain number of loss assessment approaches have been used in developing countries. These approaches provide loss estimates relatively quickly and for a relatively low cost. They are therefore well adapted to preliminary loss assessments that seek to identify critical loss points and commodities. For the sake of developing a customized PHL assessment methodology for grains in Ethiopia, our critical review has focused on the following three main approaches.

4.1.1 FAO 4-S or load tracking method

The FAO loss assessment methodology (FAO, 2015) was developed in order to support developing countries in producing nationally representative PHL estimates through a cost-effective data collection program that focuses on the critical loss points.

Therefore, methods for estimating grain PHLs were reviewed, methods and techniques for assessing PHL were synthesized, and methodological and data-collection options were tested in different countries at farm, processing, storage, and wholesale market levels. Since then, the method has been used in Kenya, Ethiopia, and Zimbabwe on different commodities (maize, wheat, sorghum, barley, haricot bean, banana, tomato, potato, mango, fish, and milk).

Assessments are carried out using qualitative and quantitative field methods. Subsequently, solutions to food losses are formulated from the results and conclusions of the assessment. The core of the assessment of food loss in a food supply chain is the acquisition of data for which the FAO methodology integrates four tools/methods, the so-called 4-S method (*screening, survey, sampling, and synthesis*). While it is suggested to use to a certain degree all four methods, the feasibility of doing so can only be determined by the researcher leading the loss assessment activity.

FAO methodology involves four data collection methods:

I Preliminary screening of food losses ("*screening*"): Based on secondary data, documentation and reports, and expert consultations (by phone, e-mail, in person) without travel to the field.

II Survey of food loss assessment ("*survey*"): A questionnaire exercise differentiated for producers, processors, or handlers/sellers (i.e., warehouse managers, distributors, wholesalers, and retailers) and other knowledgeable persons of the supply chain being assessed, complemented with ample and accurate observations and measurements. The approach combines personal interviews of key informants and group interviews. No physical measurements are planned at this stage; however, it is recommended to take photos to back up or validate the collected data. The methodology states that the statistical representativeness of respondents needs to be ensured but does not provide any guidance on how to select respondents (for example, randomly or not) or on how large the samples should be.

III Load tracking and sampling assessment ("*sampling*"): This is used for quantitative and qualitative analyses at any step in the supply chain. It aims to carry out physical measurements to assess quantitative losses. The sampling strategy for observational units (bags, grain samples, etc.) is described and involves random selections at several stages. It is also recommended to carry out an analysis of the perceived quality of the product by subjectively assigning a quality grade to the product from an established food quality scale. As this step is very demanding, it is recommended for in-depth assessment of losses at selected critical loss points in the FSC.

IV Solution finding ("*synthesis*"): This is used to develop an intervention program for food losses, based on the previous assessment methods. An evaluator identifies the cause of losses and proposes solutions to reduce them, which will feed into the development of a wider intervention program on food losses. This activity is done in consultation with the key stakeholders identified in the previous phases.

The method has been used in several African and Asian countries on several commodities; for example, in Kenya (maize, banana, milk, and fish), Uganda (maize, oil seed, and groundnuts), Cameroon (tomato, cassava, potato, and fish), Indonesia (fish), India (rice, chickpea, milk, mango, and fish), Timor Leste (rice), Ethiopia (maize, wheat, sorghum, haricot bean, tomato, potato, mango, and banana), and Zimbabwe (maize, sorghum, and horticultural crops). Based on the validation of the findings, national PHL reduction strategies have been developed.

The FAO 4-S method is comprehensive in the sense that it addresses the causes of losses and the associated prevention and mitigation measures. From a technical point of view, the 4-S method provides an interesting combination of qualitative and quantitative methods, formal surveys and focus groups, and random or purposive selection. The most interesting results are the identification of the points where most losses occur (critical loss points (CLP)), which can be used in further assessments. It is unclear, however, how this approach could be applied at a wider scale; for example, to estimate losses at regional or country scales. Furthermore, while the measurement itself is described, the methodology does not recommend any approach to aggregate or average percentage losses to reach meaningful results by commodity and chain actor. Finally, the approach does not provide guidance on the selection of the different samples and their respective size. The accuracy and precision of estimates coming from this or similar approaches are therefore difficult to assess.

4.1.2 African Postharvest Losses Information System (APHLIS)

APHLIS is a network of local postharvest experts, supported by a database and loss calculator, who provide cumulative cereal weight loss estimates from production for sub-Saharan Africa by province, by country, and by region. APHLIS was the initiative of the European Commission's Joint Research Centre and was developed by the Natural Resources Institute (UK) and German Ministry of Food.

APHLIS combines the use of secondary data (gathered through its large network of experts) with modeling to generate estimates that intend to reflect the local context and farming practices. Secondary data are used to derive percentage loss estimates at each point of the supply chain (PHL profiles) and combine them with seasonal factors on crop production, climatic conditions, farming practices, and market characteristics (among other factors) to generate absolute loss estimates.

APHLIS does not conduct field surveys to collect data needed for estimation. Instead, a network of data providers sends the loss information at its disposal to the APHLIS database. APHLIS uses the data according to its own algorithm to output loss estimates. In such a situation, it is almost impossible to gauge the quality of the loss estimates in terms of statistical variances and biases.

One of the advantages of the APHLIS system is that it seeks to make the best use of the existing information on losses, exploiting secondary data from the existing literature to establish percentage losses and combining them with key parameters that can be adjusted by users to generate loss estimates reflecting local country conditions and seasonal factors. The quality of the PHL estimates resulting from these calculations is as good as the information from these two sources.

That said, the calculation framework, as with any model, is a simplification of the reality. For example, there are several relevant independent variables not covered by the APHLIS system that also influence losses, such as agronomic practices, farm technologies, socioeconomic characteristics of holders, etc. In addition, there is the need to clarify the definition of crop production that is used as a basis for the calculations. For instance, it is important to state whether the production from a given country is potential production (derived from an estimate of potential yield) or actual production. This clarification is necessary because using potential production or actual production leads to significantly different estimates of cumulative weight losses (as these are determined by multiplying average percentage losses by the measure of production).

There is very little loss during the initial periods of storage (first three months). With APHLIS, the storage loss is standardized to a nine-month period. The majority of storage studies are about nine months long; this is the duration of a typical storage season. APHLIS presents users with both absolute and relative loss values from production. It requires data on crop production, percentage of grain lost at each link in the postharvest chain, and finally factors that might vary seasonally or annually.

It is worth mentioning that APHLIS deals mostly with estimating weight loss, and only in extreme cases does APHLIS include loss of quality (Hodges, 2013). APHLIS acknowledges that the best-quality data are considered to be the measured estimates using modern methods. APHLIS does not conduct loss assessment by itself; rather, it uses storage loss estimates from the literature and those submitted by the APHLIS network as the basis of its calculation of cumulative postharvest weight loss. The data on the extent of postharvest loss at each link in the chain come mostly from the scientific literature. APHLIS is currently operational for the delivery of weight losses estimates for cereals.

It is therefore important not only to work with figures that are good estimates at the time and in the situation they are taken but also to be aware that at other times and situations the figures will differ. This necessitates regular recalculation of loss estimates with the best figures available, a task addressed by APHLIS. This implies a regular supply of production and loss data. The APHLIS loss calculator estimates cumulative weight losses by reference to three sets of data.

A set of loss figures that represent each of the links in the value chain called *a postharvest loss profile* is considered for loss calculation from total production at the stages of harvesting/field drying, drying on platforms, threshing/shelling, transportation to farm store, farm storage, transportation to market, and market storage. The PHL profiles used by the loss calculator at the center of APHLIS are modified by four factors that may change on a seasonal basis. These are the percentage of grain marketed within three months after harvest, presence of rain at harvest, storage duration, and presence of the larger grain borer.

4.1.3 Rapid Loss Appraisal Tool (RLAT)

RLAT for agribusiness value chains was developed by the Sector Project Sustainable Agriculture (NAREN), implemented by GIZ. The methodology is designed to serve as a pre-screening for further in-depth studies and to identify leverage points for reducing losses at the various value chain stages—from farming through handling and processing to retail trade (GIZ, 2015a; b). RLAT's developers based the tool on a set of tried-and-tested participatory approaches and tools that draw on GIZ's experience of using rapid appraisal methods. The tools and approaches have been simplified for rapid implementation at the local level, enabling users to quickly and systematically collect information, assess stakeholder perceptions of food losses, and triangulate the findings using fast-track multiple evaluation methods that make it possible to confirm the results without undertaking representative sample surveys.

Its technical definitions on food losses are adapted from World Resources Institute (WRI, 2015). The RLAT methodology is similar to and works alongside the FAO's methodology on food loss assessments (4-S); however, the two methods seem to have some differences. As the name implies, RLAT is a fast-track appraisal tool that provides sufficiently accurate information for informed decision-making, whereas the FAO methodology aims to turn out a scientific database. RLAT can also be used as a prior step (pre-screening) to undertaking the FAO methodology (4-S) and can lay the foundations for more in-depth studies. It has strong reliance on a participator appraisal approach, while the FAO methodology encourages the use of both rapid appraisal techniques and sample load tracking whenever feasible. RLAT's specific focus on aflatoxin is unique, though this has been addressed as a food safety issue in the FAO method as well.

As stated by the developers of the RLAT (GIZ, 2015a; b), its purpose is to provide a sufficiently accurate pre-screening tool for identifying intervention points along agribusiness VCs, working out incentives for VC operators, and proposing measures to reduce pre- and postharvest losses. The tool supports the design of concrete interventions that have the primary aim of improving food security at the subsistence level, either on farms or in communities, and the secondary aim of upgrading specific VCs. The tool supports:

- Pre-screening of qualitative and quantitative food losses and their hotspots (critical loss points) in local/regional VCs, including self-consumed food;
- Identification of leverage points for reducing food losses along VCs (pre- and postharvest) and the gathering of sufficient evidence for initiating interventions;
- Identification of information gaps to support the planning of more detailed studies on losses and their impacts on possible loss reduction measures as well as on incentives that would engage private and public sector stakeholders in addressing food losses.

RLAT as a tool consists of three consecutive and interdependent phases divided in to ten steps. Sequential appraisals of loss hotspots realized by different sets of VC stakeholders make it possible to survey, compare, triangulate, and scrutinize perceptions about losses. Finally, inconsistencies or discrepancies in the loss perception data collected through the different activities undergo a plausibility check (i.e., are discussed by experts). The aim of this check is to formulate a shared view of the prevalence of losses along the VC and to provide realistic loss figures.

Another strong point of the RLAT is the way it ranks the postharvest loss in terms of severity and relevance in a participatory approach. RLAT supports the identification of two types of losses that can be distinguished by the time lag between cause and effect:

- Immediate loss effects that are directly felt at the moment they occur, e.g., spillage; damage caused by hail, pests, or diseases; or spoilage when corn breaks during shelling;

- Lost opportunities that are the result of inappropriate practices or unfavorable framework conditions in the upstream stages of the VC that only materialize as losses in a downstream stage of the VC.

The RLAT was tested in Ghana in 2014. The approach comprises ten steps but, excluding the preparation and report-writing steps, can be shortened into six major steps (GIZ, 2015a; b).

Step 1: Desktop study on the political, socioeconomic, and agribusiness conditions.

Step 2: Key expert workshop, including: (i) analysis of hotspots (critical loss points) along the value chain; and (ii) validation of desktop study results.

Step 3: Stakeholder workshop:
- Analysis of hotspots (critical loss points) along the value chain;
- Validation of key expert workshop results.

Step 4: Focus group meetings:
- Appraisal of the workshop results through a confrontation with observations on the ground;
- Verification of loss perceptions of VC operators.

Step 5: Key informant interviews:
- Validation and completion of results of preceding process steps.

Step 6: Assessment and presentation of results:
- Plausibility check of results at the different process steps;
- Presentation of aggregated results.

The approach encompasses group discussions and individual interviews to assess pre- and postharvest losses and their causes, and identify the main prevention and loss reduction measures. The toolbox comprises a complete set of questionnaires, procedures, and calculation methods that are more comprehensive and detailed than the 4-S approach is. Furthermore, although this approach does not aim at full statistical representativeness, it provides clear guidance on how units (villages, farmers, etc.) should be selected in order to limit potential biases and obtain meaningful results.

These guidelines recommend using this approach as part of the preliminary assessments that need to be carried out in preparation for more in-depth studies. This type of assessment approach can also be used to complement standard survey-based methods, e.g., to better understand the socioeconomic dynamics underpinning farming practices and their effects on losses, and to collectively identify the most efficient and adapted prevention and mitigation measures. Finally, the RLAT could also be used as part of the monitoring and evaluation of policies and interventions in the field of food losses.

RLAT supports the assessment of losses along agribusiness VCs, from production, harvesting, and handling, through aggregation, wholesale trade, and processing, all the way up to retailing. Assessing waste occurring at the consumption level is not part of the tool. Moreover, unlike the FAO methodology, data are not segregated into quantitative and quantitative data.

The RLAT includes biophysical measurements and an aflatoxin assessment; however, it is more skewed to storage condition and tends to ignore what happens at other functional stages of the value chain. Moreover, the analysis of samples for aflatoxin would remain expensive for any African country, including Ethiopia.

4.1.4 Methods of loss assessment due to bio-deterioration

The gravimetric or the count and weigh (C&W) method

The method involves separation of grain samples into damaged and apparently undamaged or sound grains, counting and weighing each, and calculating the percentage weight loss using the following formula:

$$\% \text{ weight loss} = \frac{(UNd) - (DNu)}{U\ (Nd + Nu)} x100$$

Where U = the average weight of undamaged grain, Nd = number of damaged grain, D = the average weight of damaged grain, and Nu = number of undamaged grain.

This method seems the easiest to conduct since no moisture control readings are necessary (Adams and Schulten, 1978), and it involves a smaller sample. It provides an estimate of loss where a baseline cannot be determined at the beginning of the storage period and uses only minimum equipment. It is less laborious (Boxall, 1986). However, Adams and Harman (1977) used the method in Zambia and noted the problems of variation in grain size, of variation in average grain weight for damaged grain at high levels of infestation, and of counting grains with internal infestation as undamaged. The estimate will only be valid if the damaged and undamaged sub-samples are closely comparable in original size of grain. If, for instance, the insects prefer the larger grains, the mean weight of damaged grains could exceed that of undamaged grains, resulting in a negative estimate of loss. However, they suggested that it might be of use in single-visit surveys, especially with smaller grains of more uniform size that are not liable to multiple infestations and for infestations without internal feeding stages (Adams and Harman, 1977). In order to address the problem of variation in grain size, Boxall (1986) suggested dividing the sample into different grain size categories using a suitable set of sieves before separating the damaged and undamaged fractions. After counting and weighing grains in each fraction size category, the weight loss can be calculated as follows:

$$\text{Weight UN} = \frac{(\text{WULG})}{(\text{NULG})} x\text{TNLG} + \frac{(\text{WUSG})}{(\text{NUSG})} x\text{TNSG}$$

Where weight UN = weight of undamaged reference sample, WULG = weight of undamaged large grains, NULG = number of undamaged large grains, TNLG = total number of large grains, WUSG = weight of undamaged small grains, NUSG = number of undamaged small grains, TNSG = total number of small grains.

This was believed to improve the figure for weight loss obtained by the C&W method and overcome the absurdity of negative values for percentage weight loss. Besides, De Lima (1987) indicated that by dissecting a representative sample of grains, hidden (internal) infestation can be taken into consideration. Pantenius (1987) found the method to be the best adapted for loss assessment, despite the weaknesses, especially with the modifications (categorization of sample grains by size) proposed by Boxall (1986).

Modified C&W method: The method described here is for maize, but a similar approach can be implemented for other grains. It consists of the following eight steps.

Step 1: A sample of maize cobs is taken in the same way as in the conventional method. According to experience, samples of 30 cobs have been found to provide reasonably precise results.

Step 2: The cobs are shelled one by one, and the number of destroyed and missing grains is recorded for each cob and then summed over all 30 cobs to obtain the total number of destroyed and missing grains (TND). If desired, cob-related characteristics such as husk cover and grain type can also be recorded at this point. For consistency purposes, the criteria used to define "destroyed grains" should be clearly specified and rigorously followed. For example, destroyed grains can be defined as those that are crushed during shelling into fragments smaller than one-third of a grain, or which passed through a 3.35 mm sieve in Step 3. All such fragments must be thrown away to avoid double counting later.

Step 3: The shelled grains from each cob are sieved through a standard sieve set (for example, 3.35/2/0.85 mm mesh). If desired, the number and species of insects on each cob can be recorded at this point.

Step 4: The sieved grains from all cobs are then pooled. A typical pooled sample contains 7,000 to 15,000 grains and weighs from 1.5 kg to 3.5 kg. The pooled sample is weighed, and the weight is recorded to the nearest gram. This is the final weight (FW).

Step 5: A riffle divider is used to subdivide the pooled sample several times to obtain two subsamples containing about 400 to 600 grains each. Remaining grains are discarded. The number of grains per subsample should be increased if there is a high proportion of damaged grain, because it is the total number of undamaged grains that primarily determines precision. A minimum of 50 undamaged grains per subsample is suggested.

Step 6: The grains in each subsample are separated into two groups, damaged and undamaged, by eye as in the conventional method.

Step 7: For each subsample, the groups of damaged and undamaged grains are counted and weighed as in the conventional method to obtain the quantities Nd, Nu, D, and U. Wd and D are used interchangeably to mean weight of damaged grains, and also Wu and U to mean weight of undamaged grains. In this case, use D and U as in the formula below instead of Wd and Wu.

Step 8: The percentage weight loss is then calculated using the following formula:

$$\frac{\text{TND (D + U) U + FW (Nd U- Nu D)}}{\text{TND (D + U) U + FW (Nd + Nu) U)}}$$

Where TND = total damaged grains, D = weight of damaged grains, U = weight of undamaged grains, FW = final weight, Nd = number of damaged grains, Nu = number of undamaged grains.

Weight loss is calculated separately for the two subsamples, and the average of these two values is taken as the estimated weight loss in the sample of cobs.

The percentage weight loss in the sample is defined as:

$$\text{Percentage weight loss} = \frac{Undamaged\ weight\ (UW) - Final\ Weight\ (FW)}{Undamaged\ Weight\ (UW)} x100$$

This method is quite cumbersome and therefore may not be recommended for large-scale assessment or surveys.

Standard chart method: To estimate the weight loss for maize stored in grain form, the enumerator uses a standard chart. The procedure is as follows.

Step 1: A reference relationship between the number of damaged grain in a given sample and percent weight loss must first be established. This requires:

- The collection of grain samples of differing qualities from the farmers or traders some time in advance of the beginning of the survey fieldwork;
- Then, in a specialized laboratory, the analysts will separate, count, and weigh the damaged and undamaged grain using the C&W methods presented previously, for each grain quality class;
- The percentage weight loss will be calculated using the methods presented above;
- A regression line is fitted between weight loss (y) and the number of damaged grain (x) (GSARS, 2018).

Step 2: In the field, the enumerator randomly selects separate samples of, for example, 100 grains each from the farmers' maize. The enumerator then places the grains in a liter plate to count the damaged grain. The process is repeated for the samples, and an average number of damaged grains per 100 grains is established.

Step 3: The number of damaged grain is read off against a predetermined regression chart to find the percentage weight loss. For example, using the chart above, if the enumerator has established an average of 10% damaged grain from the samples he selected, he will attribute a percentage weight loss of 1.5%.

Visual scales method: Most of the techniques presented involve collecting grain samples from the farmers, sending them to laboratories for analysis, and later returning them. This back-and-forth of grain samples delays the compilation of the loss estimates and the publication of the results of the surveys. The visual scales method has proven to be rapid and easy to use for both enumerators and respondents. The precision of the results was shown to be similar to that of competing methods. However, visual scales are only "rapid" in that the scales are prepared in the laboratory first and standard charts are established before the fieldwork takes place.

Visual scales and standard charts allow for a rapid and relatively accurate determination of losses directly on the field or in the farm. Visual scales, which have been commonly used in loss assessments since their development in the 1990s (Compton, 1991), are presented here for the loss assessment of maize in cobs; however, they could also be applied to other grains or commodities, with some adaptations and variations. The visual scales method usually involves the following steps.

Step 1: Different classes of pest infestation of maize cobs (scales) are defined. This is typically done by agricultural technicians by sorting and re-sorting a pile of insect-damaged maize cobs into visual classes, roughly reflecting the categories that farmers are used to, until a consensus is reached on the limits of each class.

Step 2: A weight loss parameter is associated with each class of pest infestation. These parameters are determined in advance of field work by means of laboratory analyses using loss assessment techniques, such as the TGM or the C&W method.

Step 3: A visual print of the different classes and associated weight loss parameters is prepared and handed to the field teams that will carry out the assessment.

Step 4: For each storage facility selected (on- or off-farm), the enumerator takes a sample of cobs and matches the cobs with the various classes of infested cobs portrayed in the pictures. The enumerator determines the number of cobs assigned to each class.

Step 5: The weight loss for any given unit (farm, village, enumeration area, etc.) is calculated by taking an average of the weight loss parameters recorded (*W1, W2, W3*, etc.) weighed by the share of the cobs in each class in the total number of cobs sampled (N1/NT, N2/NT, N3/NT, etc.).

$$\text{Visual weight loss} = \frac{aN_1 + bN_2 + cN_3 + dN_4 + eN_5}{N_T}$$

Where N1–N5 = number of cobs in classes 1 to 5 in sample; NT = total number of cobs in sample, and a–e are damage coefficients (i.e., % weight loss associated with each class).

The advantages of visual scales are that they:

- Avoid the need to return samples to the laboratory;

- Avoid time-consuming laboratory analyses (weighing and counting grain, and determining its moisture content, etc.);
- Increase the number of samples that can be assessed;
- Avoid taking grain from farmers;
- Involve farmers in the assessment;
- Link the assessment to both weight and quality (value) loss.

A visual scale can be used to assist loss assessment at any link of the postharvest chain where there has been bio-deterioration, but the method gives no measure of losses due to scattered or spilt grain or those grains completely removed by rodents, birds, etc. Although it is rapid and does not involve weighing and counting grain and determining its moisture content, etc., it is less accurate than other methods. However, visual scales have many advantages, not least of which is their ease of application that allows for a much large sample of farms. This is important, as the extent of losses varies greatly between households, between geographical locations, between seasons, and between years. When attempting to provide an overview of the extent of losses, it is believed that the larger sample size will more than compensate for the reduced accuracy of individual measures. The findings of Utono (2013) indicated that the visual scale method is comparable to conventional methods of assessing weight loss and can be used as a rapid method of assessing the degree of damage to grain and proportional loss for sorghum, millet, and threshed maize. Details on the development and implementation of loss surveys using visual scales are available in Hodges (2013).

The volumetric/bulk density or standard volume weight (SVW) method

This method seeks to compare the weights of a standard volume of damaged and undamaged grain and to measure the percentage loss using the following formula:

$$\%\ \text{Weight Loss} = 100\ x\ \frac{(\text{U} - \text{D})}{\text{U}} x\ VU/VD$$

Where U = weight of undamaged grain, D = weight of damaged grain, VU and VD = the respective volumes of grain.

The principle is to establish the condition of grain at the beginning of the storage season and to compare the condition of grain samples collected throughout the season with this baseline condition (Adams and Harman, 1977; Boxall, 1986). The weight of grain occupying a standard volume container, determined from a sample collected at the time of storing, represents the baseline. Losses are recorded by following changes in the weight of grain occupying the same standard volume on subsequent occasions. It is assumed that when grains are dropped into the weighing bucket, the volume occupied by the same number of undamaged and insect-damaged (hollowed) grains will be the same, but the weight of the latter will be less (Boxall, 1986).

In practice, this method involves taking a representative sample of grain (or cobs, bundles, etc. that will then be shelled/threshed) from a given storage unit, separating damaged from undamaged grain, and measuring the volume and weight of each sample. Damages made by grain-boring insects result in a lower density (mass in a given volume) of the sample of damaged grain as compared to the sample of undamaged grain.

The volumetric method is not exempt from biases, especially when damage levels are high. In this case, damaged and undamaged grains may fall and be packed differently in each container (for example, some damaged grains may break), leading to a significant difference in the number of grains required to fill a given volume and thereby distorting the density comparisons.

To allow for the effect of moisture on the volume of the grain, it is necessary to calculate by experiment the dry weight of a standard volume of a reference sample of grain at different levels of moisture content. The dry weight of grain filling the standard volume container for subsequent samples taken at the prevailing moisture content can then be related to the dry weight of the reference sample at the same moisture content, by reference to a specifically prepared graph or chart (Adams and Harman, 1977; Boxall, 1986).

The thousand grain mass (TGM) method

The TGM is the mean grain weight multiplied by 1,000 and corrected to a dry weight, and is calculated by counting and weighing the number of grains in a working sample. The sample is not adjusted to a specific weight or number of grains and therefore avoids a source of error or bias (Proctor and Rowley, 1983; Boxall, 1986). The method involves the determination of a reference TGM from a sample of grain collected in a representative manner at the beginning of the storage season and comparison with subsequent measurements throughout the season. The weight loss in a sample of grain is given by the formula:

$$Weight\ Loss\ (\%) = \frac{Initial\ TGM - Sample\ TGM}{Initial\ TGM} x100$$

Proctor and Rowley (1983) and Boxall (1986) indicated that in the farm-level loss assessment study, the sample of grain collected at the beginning of the season must be representative of the entire quantity of grain stored, and the subsequent samples are collected from the quantities of grain removed for consumption and are therefore representative of those quantities alone. The regular samples collected throughout the season are therefore not strictly comparable to the baseline, and there may be wide differences in the composition of the sample (e.g., proportion of large to small grains).

The multiple TGM technique has been proposed to take account of variations in grain size and difficulties in obtaining representative samples (Proctor and Rowley, 1983). When the initial sample is collected and before counting and weighing grains to calculate a TGM, the sample should be separated on the basis of grain size into as many size groups as seems necessary (Proctor and Rowley, 1983 and Boxall, 1986). Then the TGM is calculated for each group. By recording corresponding TGMs from subsequent samples, sample weight can be corrected before calculation of the weight loss. After determining the TGM for each size group in subsequent samples, the potential weight of each size group is calculated as follows:

$$Potential\ Weight\ (WP) = \frac{TGM1}{STGM} x WGSG$$

Where TGM1 = initial TGM, STGM = sample TGM for a grain size group, WGSG = weight of that grain size group.

The percentage loss is then calculated from the formula:

$$Loss\ (\%) = \frac{Wp\ (large) + Wp\ (small) - WGSG\ (large) + WGSG\ (small)}{Wp\ (large) + Wp\ (small)} x100$$

The method is independent of internal infestation and in that respect overcomes one of the disadvantages of the C&W method (Adams and Schulten, 1978) and the SVW method (Boxall, 1986). Difficulties arise if the proportion of broken grains changes significantly between successive samplings (Adams and Schulten, 1978; Pantenius, 1987). The need for a baseline (reference) sample collected at the beginning of the storage season makes its application difficult (Boxall, 1986).

The converted percentage damage method
This involves determination of the percentage of insect-bored grains in a sample and its conversion to a percent weight loss by dividing it by a predetermined conversion factor (C) or multiplying it by 1/C.

The conversion factor is calculated from the formula:

$$C = \frac{Percentage\ Bored\ Grains}{Percent\ weight\ loss}$$

The percent weight loss is calculated using the figures from the C&W technique.

This method was proposed as a way of obtaining a quick appraisal of losses caused by grain-boring insects. It involves determination of the relationship between the percentage damage and weight loss by a laboratory experiment. Tables should then be constructed for use in the field. Once the relationship between percentage damage and weight loss has been established, a conversion factor can be calculated and subsequently applied to field samples of the same variety infested by the same insect pest (Adams and Schulten, 1978; Boxall, 1986). Adams and Schulten (1978) recommended that the percentage damage-weight loss relationship (the conversion factor) be calculated from the formula by using the figures from the C&W method. Boxall (1986) suggested that there is no reason why other methods (e.g., SVW) should not be used. The conversion factor is calculated from the above formula as:

% weight loss = percent damaged grains /C or percent damaged grains x 1/C

The principle is the same as that for visual scales (associating a certain percentage of weight loss to a certain degree of damage) but is restricted to insect-related damages, while visual scales can for example combine damages made by insects and molds, and is not accompanied by any visual aid. Although the method is liable to the same sources of error as the SVW and the C&W methods, it has yielded good results in practice. Hence, it is recommended instead of guessing when the two methods mentioned above cannot be used.

Some approximate conversion factors have been established. They all relate to cases where larval stages of insects develop within grains; for example, weevils (*Sitophilus* spp.) and Angoumois grain moth (*Sitotroga cerealella*) infestations (see Appendix Table 4). They are only approximate and should be regarded as rough guide; it is preferable to determine conversion factors for the particular grains being studied.

4.1.5 Other protocols and systems
In addition, there are other protocols and assessment systems that are less widely used. These include the food loss and waste (FLW) Standard Protocol (WRI, 2016), which is used to account for the physical amount of FLW, expressed as weight. The FLW Standard (Version 1.0) does not include provisions for how to quantify losses that occur during pre-harvest. There are many ways in which an entity can quantify FLW. The FLW Standard provides guidance on ten possible quan¬tification methods, including but not limited to weighing, waste composition analysis, mass-balance calculation, and surveying. The FLW Standard also lays out require¬ments for reporting key assumptions (e.g., about sam¬pling, scaling up data, and assessing uncertainty). The Standard has ten steps that require one to define goals, review accounting and reporting principles, establish scope, decide how to

quantify FLW, gather and analyze data, calculate inventory results, assess uncertainty, perform review (optional), report FLW inventory, and set target and track over time (optional).

4.2 Review of postharvest loss assessment methodologies used in Ethiopia

In sub-Saharan African in general and in Ethiopia in particular, research on postharvest loss assessment is very limited. Based on available literature, out of the loss assessments carried out, only 0.3% of the assessments are based on primary data, and many are based on secondary data generated using different modeling approaches.

Some studies on postharvest loss followed rapid appraisal techniques (Tadesse and Regassa, 2013), and a few employed case studies (FAO, 2017, unpublished). There are also quite a number of studies that did not mention the type of methodology employed but depended on the consent of stakeholders, mostly farmers (Chichaybelu et al., 2015; Beyene and Ayalew, 2015). Earlier studies by McFarlane (1969), Boxall (1974, 1998), Kidane and Habteyes (1989) as well as many recent studies by Tadesse (1991, 2003, 2005), Ashagari (2000) and Bachewe et al. (2018) focused on storage losses. Studies on postharvest losses of cereals and pulses in storage were reviewed and compiled by Tadesse et al. (2008).

Many designed studies were conducted regarding storage of grain crops, including assessment of prevalence of storage pests (Sori and Ayana, 2012; Dubale et al., 2015; Tsedale, 2016; Shiferaw, 2017), efficacy of botanicals and inert materials on storage pests (Firdissa and Abraham, 1999; Tesfaye and Gautam, 2003; Mekuria, 1995; Gebriel and Hundie, 2006; Gemechu et al., 2013; Kidane and Jembere, 2010; Ibrahim, 2015; Gebreegziabiher et al., 2017; Alemnew, 2017; Shiberu and Negeri, 2017) and comparison of storage structures (Lemmesa, 2008; Belayneh, 2014; Jobir and Fetene, 2014; Yeshaneh, 2015; Mulu and Belayneh, 2016).

AGRA (2014) assessed the status of postharvest losses and storage for major staple crops in eleven African countries, including Ethiopia, following the value chain—harvesting, de-husking, threshing/shelling, drying, parboiling, storage of raw produce, packing/bagging, transport/loading, processing/milling, and storage of processed produce. Bachewe et al. (2018) conducted assessment of postharvest losses of major cereal crops in major regions of Ethiopia and employed probit modeling estimates of associates of storing crops. Moreover, to determine whether and to what extent the factors influence losses during storage, they used a Tobit model.

In terms of spatial coverage, many were confined to very limited area (Boxall, 1974; Tadesse 1991, 1997; Tadesse et al., 1993), while quite a few had wider coverage in terms of area representation (Kashi, 1985; MoARD, 2010; Tadesse, 2005; FAO, 2017). Recent studies by FAO (2013a, b, c, d, and e; 2016) covered major regions (Amhara, Oromia, SNNP, and Tigray) in Ethiopia.

There are great practical, methodological, and conceptual challenges to accurately measuring PHLs at farm level (Parfitt et al., 2010; Hodges, 2013; Affognon et al., 2015). Most researchers in Ethiopia conducted their storage studies using the C&W method, while Tadesse (n.d.) compared the C&W, SVW, and TGM methods.

An overall review of the studies conducted in Ethiopia shows that there are only few studies that tried to assess postharvest losses in grains following the value chain approach and covering a wider geographical coverage. In 2017, FAO (2017, unpublished) conducted postharvest loss assessment of maize, sorghum, wheat, and haricot bean in Amhara, Oromia, SNNP, and Tigray Regions following the FSC approach.

5. PROPOSED METHODOLOGY FOR PHL ASSESSMENT OF GRAINS IN ETHIOPIA

Different PHL assessment methodologies are available to determine the extent and causes of losses along the different stages of the postharvest system. The choice of which methodology to use, however, depends on the scope of the assessment, the level of expertise, and availability of logistics to undertake the assessment. Cognizant of the huge expense associated with the conduct of large-scale postharvest loss assessment, it is recommended to have rapid loss assessment using RLAT or RAT (Rapid Appraisal Tool) at first in order to have an overview and then plan subsequent comprehensive PHL assessment (FAO methodology and the present customized methodology). The rapid appraisal tools described in RLAT are very clear and detailed to implement, and hence they have been used in the preparation of the customized methodology. The FAO methodology is very appropriate for an in-depth assessment of losses at selected critical loss points of the FSC. Results of such assessments can then be fed into a model (e.g., probit, Tobit, etc.) in order to adjust loss estimates to the prevailing scenarios and predict expected extent, causes, and determinants of PHL.

The approach that we opt for should, however, be convenient for enabling postharvest loss assessments along the different functional stages of major crop value chains. In this effort, all pertinent stakeholders who operate in the value chain as major actors, supporting institutions, or input providers (producers, collectors, wholesalers, retailers, transporters, subject matter specialists, researchers, financial institutions, technology fabricators, service providers, etc.) need to have active involvement during data collection and validation of the findings of the assessment.

It is strongly recommended that this customized methodology be put to a trial testing so that all necessary improvements can be made in order to fine tune and make it more practical and cost effective. Ultimately, it should generate information that can provide essential justification and motivation for introducing measures deemed necessary to prevent and reduce postharvest losses of grains. Assessment will be made along the functional stages of the value chain, though the consumption stage has not been included, as the major concern in Ethiopia is food loss rather than food waste. The methodology consists of: planning and preparation for the assessment; desktop study; conducting the field survey (semi-structured interviews (SSIs), key informant interviews (KIIs), focus group discussions (FGDs) and stakeholder validations); load tracking; summary of PHL; and formulating solutions. The customized methodology is a blend of salient aspects of different methodologies reviewed, such as the strong attributes of RLAT, particularly its participatory approaches, and the sound approaches of the FAO methodology for identifying major FSCs and quantifying losses through load tracking and assessment of feasibility of loss reduction interventions. It also inculcates the commonly accepted methods of loss assessment stated by APHLIS, which in turn relies so much on recommendations of Hodges and Stathers (2012).

5.1 Planning and preparations for loss assessment

At this stage, we make sure that a multidisciplinary team is set up to conduct the postharvest loss assessment. Ideally, the team should possess a blend of complementary knowledge (e.g., of the current status of the VC, from farm to fork, and of agribusiness economics) and skills (e.g., in workshop moderation and the use of other participatory tools). Preferably, the team will include experts from agribusiness/agricultural economics, crop protection, and postharvest management. The team as well as the facilitators to be deployed must have very good familiarity with the general conceptual framework of postharvest loss, types, and causes. More importantly, they need to know the practical implementation of the methodology and use of participatory tools.

It is very important to allocate sufficient time and arrange the necessary resources for the upcoming assessment mission. In addition, contacts are made with different stakeholders for upcoming events. The trainers of users and facilitators should touch base on all the stages of the methodology to build capacities of participants for analyzing and structuring the information gathered and for capitalizing the results.

5.2 Desktop study

The desktop study is an obligatory step, made in order to have a rough idea of the range of losses and some main causes. The main purpose of the desktop study is to provide the baseline in a particular area, zone, or country and to develop an understanding of the structures of the selected VC, the product flows, and the processes at each stage of the VC, called “functions” or stages, where losses may be occurring. Secondary research can provide a preliminary overview of potential loss points, type and extent of losses, and potential causes and corresponding solutions. Data are then cross-checked in hotspot analyses, which are conducted in the key expert roundtable or key informant interviews, stakeholder workshops, and focus group meetings. These will provide an overview of the FSCs in the subsector and subsequently enable us to make a selection of one (or more) FSC(s) for surveying and sampling (FAO, 2015). Once the major FSC is selected, then a flow diagram has to be drawn. This diagram includes the production inputs, for the sake of documenting eventual waste or impact on environment.

The information sought through the preliminary screening should allow for the study leader to construct a thorough scheme showing the diverse paths in the food supply chains of the selected food product, highlighting the role of the actors rather than the activities. The product flow in the supply chain shows the amount of product (in %) moved from each actor to the different subsequent actors or utilization points.

Finally, the exercise should pre-identify the CLPs or loss hotspots in the FSC so as to provide more emphasis during the subsequent steps of surveying and sampling. In this way, the researchers can prioritize their visit to the most critical stages of the FSC and optimize efficiency. It is important to remember that CLPs are stages or points in the FSC where food losses have the highest magnitude, the highest impact on food security, and the highest effect on the economic result of the FSC.

5.3 Field research phase: actual survey work

Survey implies making observations of the FSC right in the field and conducting interviews with the FSC actors. It is a tool that relies heavily on the internal assessment of the actors in the chain.

The survey should be sensitive and detailed enough to identify more clearly quantitative and qualitative information than what has been gathered during the preliminary stages. For issues pertaining to how to plan and conduct surveys, please refer to GIZ (2015a) and FAO (2015). Information can be gathered from key experts, either through a key expert roundtable or individual key informant interviews.

Key expert roundtable

The main objective of the key expert roundtable is to bring together highly qualified and/or experienced people from different disciplines who are relevant to the loss debate in general and to the selected agribusiness VC in particular. The main purpose is to generate detailed data on losses (especially causes, economic and social impact, and potential solutions), validate, cross-check, and build on information from group interviews and observations, and provide case studies describing examples of the causes and effects of losses. The information retrieved from the SSI and the observations should be recorded in output matrices.

According to RLAT, the loss hotspot analysis is an effective tool for triggering discussions among participants on different loss perceptions in specific VC functions. In this way, it facilitates a common understanding of critical loss points along a particular VC.

Key informant interviews

Key informant interviews are used to cross-check, supplement, and/or deepen information gathered in the previous process steps. They also serve to verify specific issues that (a) could not be discussed in depth during the key expert roundtable, stakeholder workshop, and focus group discussions due to time constraints or (b) remained controversial and for which no common understanding could be reached.

Stakeholder workshop

Conducting stakeholder validation right in the field is highly recommended by RLAT and FAO. A stakeholder workshop is used to validate and further complement the results of the key expert roundtable and desktop study. Participants predominantly come from the survey zone and, together, should constitute a balanced cohort of practitioners from the farming, trading, and processing stages of the VC and also from public and private advisory services, local authorities, development programs, and other relevant organizations. This is essential for collecting sufficiently diverse views on the actual situation of losses occurring along the VC in question.

Focus group discussion (FGD)

FGD is an inexpensive rapid appraisal technique used for holding guided discussions with small groups of operators from a specific stage of the VC (producers, traders, processors). Meetings with processors are not always held as focus group discussions but can instead be one-to-one interviews.

Combining guided discussions with participatory methods, such as transect walks or the loss categories and loss ranking matrix, is very useful for promoting discussion on and understanding of loss issues and their impacts on VC operators at different stages of the VC. In principle, focus group discussions should take place near the locations where losses usually occur so that a transect walk can be undertaken. This technique enhances discussions and provides a sound footing for a realistic assessment of the product flow and critical loss points.

5.4 Load tracking and sampling (sampling)

Though details on how to measure losses during load tracking are not detailed as in GSARS (2018), this stage is typical of FAO methodology (FAO, 2015). Physical measurements can be undertaken to estimate both losses incurred during on-farm operations and those arising during off-farm storage, transport, processing, distribution, selling, and any other point of the chain.

Load tracking is a common approach to use along part or all of the food supply chain. It generates data with a high degree of accuracy but is expensive and time-consuming. It would most likely be used when there is a need to gain in-depth knowledge of food loss and waste in a particular location and for a particular crop. If there is an opportunity, it is encouraged to take actual measurements of food losses; for example, by sampling a harvested area or a product batch and taking the weight of the lost product as a percentage of the total product. As a general guide, we could say that three replications at each of two or three different sites, times of the year, or rainfall conditions would be sufficient. However, it will be up to the conditions in the FSC and the researchers' judgment to decide whether this is feasible within the time frame of the study (GSARS, 2018).

GSARS (2018) details practical steps in conducting load tracking and suggests that physical measurements should be undertaken for the critical stages at which on-farm losses are likely to occur. The critical stages of grains loss at farm-level are harvesting, threshing/shelling, stacking, cleaning/winnowing, drying, and storage. Transport, processing, packaging, and handling are more relevant for off-farm actors.

Losses during harvesting

While bio-deterioration generally occurs during storage, losses due to mechanical damage, scattering, or spillage are characteristics of the different post-production operations, from harvest to processing. Physical measurement techniques for each of these stages are described below. These methods are relevant for farming operations mostly done manually, as is still the case in the traditional sector in developing countries like Ethiopia. Measurement methods for mechanical processes are provided under the section that deals with losses associated with the use of combiners.

Harvest and immediate postharvest operations may be manual (involving the use of large amounts of labor) or partly mechanized or fully mechanized, as is the case when using combine harvesters for wheat, maize, and sorghum. This subsection describes a possible approach to assess harvest losses using physical measurements.

Step 1: Crop harvesting plots (subplots) are marked at random in each selected field before harvesting. Two subplots in a field can be marked if time and resources allow. If only one subplot is marked, a sufficiently large sample of fields for each targeted crop needs to be selected to allow for sufficient observations. The size of the subplots varies according to the crop and local practices. GSARS (2018) suggests, for cereals, typical sizes of 10 m x 5 m, 5 m x 5 m, or smaller for crops with higher densities such as rice.

The method followed by Guisse (2010) cited by GSARS (2018) to assess PHL of rice can be similarly employed for harvest loss assessment in similar cereals. Skilled harvesters are hired to harvest a given area in their own usual way of harvesting using sickle harvesting. Leftover crops on the harvested plots are thoroughly collected, cleaned, dried, weighed, and stored in a cloth bag. Percentage harvesting losses will be determined by the weight of crop left on the harvested area divided by the total harvested of that particular area multiplied by 100.

Step 2: As soon as the crop is physiologically mature and some time before harvesting the field starts, the team of enumerators picks up grains, ears, or cobs on the ground from the subplots marked/identified for crop harvesting. This amount will be weighed and recorded as the amount of pre-harvest losses.

Step 3: The subplots are then harvested according to the usual practices of the farmers in the study area, and the yield is weighed and recorded.

Step 4: After the harvested produce is removed from the subplot, all grains shed or missed, as well as all cobs and ears remaining on the ground, are collected and weighed separately. This quantity will be used to estimate the losses during harvest for this subplot.

While the losses occurring during harvest are estimated from the yield obtained from the crop-cutting plot, it is recommended that the estimation of losses for the various postharvest stages be assessed on the basis of a sample of the farm's total produce.

Losses during stacking

The following measurement method comprises a series of operations. First, a sample of the stacks is randomly selected in the farm's fields. Second, when the stacks are removed, after a time consistent with the farmer's practices, the scattered grains are collected, put into plastic bags, and weighed. Third, the percentage loss is calculated as the ratio between the amount lost and the quantity of grain obtained after threshing the selected stacks, adjusting for differences in moisture content if the threshing is done well after the removal of the stacks.

Losses during threshing or shelling

A standard method for measuring losses during threshing/shelling is the following.

Step 1: A sample of the farm's harvested produce—for example, 50 to 100 kg—is randomly selected and threshed according to the farmer's practices. Although manual threshing is still common in developing countries, including Ethiopia, it is progressively being replaced by mechanical threshing. The threshing can occur immediately after harvesting or after a drying period, depending on the farmers' usual practice. The grain after threshing is collected and weighed. The residual straw is also collected and weighed.

Step 2: The remaining straw is carefully examined for grains remaining in it. To do this, a sample of straw is usually taken—for example, 1 to 5 kg—depending on the crop. In this sample, the remaining grains are collected, counted, and weighed. In the case of maize shelling, losses may be due to grains remaining on the cob or damage caused to the grain by the shelling method applied. The technique for assessing the loss of maize on the cob is similar to assessing threshing losses as shown above. Usually the loss is expressed as a percentage of the total weight of the grain; some researchers, however, have chosen to express it as a percentage of the weight of shelled grain. To improve the robustness of the estimates, several samples can be taken and an average over the different samples of grain weight remaining in the straw recorded.

Step 3: This quantity is then expanded to the total quantity of straw obtained from the threshing of the 50 to 100 kg sample of produce and divided by the quantity of produce brought to threshing: this is the estimate of percentage losses at threshing. All of the information collected (number of bundles threshed, weight of grain after threshing, weight of straw, number and weight of grain remaining in the straw, etc.) should be recorded.

This measurement method is appropriate both for manual processes as well as for losses incurred when using mechanical threshers or shellers (GSARS, 2018). However, it does not take into account two types of losses that may occur during the threshing: losses due to scattering and spillage on the threshing floor and those due to damaged grain, significant sources of losses when using mechanical processes.

It could be useful to examine grain damage caused by the shelling process, possibly to provide an indication of the efficiency of the shelling instead of an estimate of food loss. It can also be used for qualitative loss assessment to understand the reduction in the value of the particular produce. In that case, shelled grain is grouped as a representative sample of a minimum of 200 grains and examined for damage in order to express the number of damaged grains as a percentage. Then a second sample of cobs is hand-stripped and a sample of 200 grains observed as previously to constitute a check of shelling damage.

Losses during cleaning/winnowing
The process for estimating grain losses during manual winnowing operations is analogous to the method used to determine threshing losses.

Step 1: The grain obtained after threshing the sample of harvested crop is winnowed according to the common practice used by the farmers. The output of this process will be an amount of clean grain and a residual amount of chaff (husks, plant material, stones, etc.). Both amounts are weighed.

Step 2: The chaff is carefully examined for remaining grains. To do this, a sample of chaff is usually taken, for example of approximately 500 g to 1 kg. In this sample, the remaining grains are collected, counted, and weighed. To improve the robustness of the estimates, several samples can be taken and an average over the different samples of grain weight remaining in the chaff recorded.

Step 3: This quantity is expanded to the total chaff resulting after the winnowing process and divided by the total amount of grain cleaned: this is the measure of percentage losses during winnowing. The data collected are recorded on survey forms similar to the one presented for threshing.

Estimation of losses when combine harvesters are used
The estimation of losses associated with the use of combine harvesters typically involves relatively complex and lengthy experimental designs on small samples of fields. The methods vary in sophistication, especially regarding design and sample selection, but usually involve:

- Estimating pre-harvest losses for any given field by setting up at least two randomly selected crop-cutting plots (for example, 5 m x 5 m) and collecting the grains that have fallen in these plots prior to the start of harvesting;
- Harvesting the whole field with the combine harvester;
- After harvesting, setting up two new randomly selected crop-cutting plots and collecting all grain that has fallen in these plots and that remaining on stalks.

The difference between the grain weights recorded after and before harvesting is an estimate of the quantity of grain losses at harvesting. The following formula used by Alizadeh and Allameh (2013) cited by GSARS (2018) can be used for this purpose.

$$HL = \frac{(L1 - L0)}{Y} x100$$

Where HL is the percentage harvest loss, L1 is the grain weight loss recorded after harvest, L0 is the grain weight loss before harvest, and Y the grain yield. L1, L0, and Y must be expressed in the same units, such as kg.

The same authors suggested that threshing losses can be determined by spreading a wide plastic sheet over a flat surface and placing a thresher on it. In experiments, the threshing chamber needs to be fed uniformly. Afterwards, all grains and panicles on the plastic sheet are gathered and weighed. The percentage weight loss at harvest is computed by the following formula:

$$TL = [L/ (T+L)] * 100$$

Where TL = threshing loss in %, L = the weight of grain thrown out through the different parts of the thresher, T = the weight of grain collected of the main outlet.

Details can be found in Alizadeh and Allameh (2013), cited by GSARS (2018).

The steps recommended to estimate grain loss when combines are used are as follows.

Step 1: Measurement of pre-harvest losses in an area of 2.0 m^2 of standing crop.

Step 2: Measurement of the total losses behind the combine after it was running in the field at full capacity and at normal operating speed. This loss will be measured across the full width of the combine header in a rectangular pattern of sufficient length to provide an area of 2.0 m^2. All loose grains and those in loose panicles/pods on the ground will be picked up, as well as any grains in panicles/pods still attached to stalks. This quantity of grain will be placed in a plastic bag, labeled, and taken to the lab for weighing and moisture adjustment.

Step 3: The combine loss is calculated by subtracting the pre-harvest loss from the total loss:

$$HL = \frac{(L1 - L0)}{Y} x100$$

Where HL is the percentage harvest loss, L1 is the grain weight loss recorded after harvest, L0 is the grain weight loss before harvest, and Y the grain yield. L1, L0, and Y must be expressed in the same units, such as kg. A very good case study is given by Paulsen et al. (2013).

Losses during drying of grains

The loss that occurs during stacking and drying unthreshed harvest has been dealt with in the preceding section. However, there are cases where grains need further drying to safer moisture levels. To estimate losses at this stage, the following information needs to be collected:

- Quantity of grain initially spread out for drying (weigh-in);
- Moisture content of the grain immediately before drying;
- Quantity of grain collected after drying (weigh-out);
- Moisture content of the grain collected immediately after drying.

In practice, in order to measure physical losses of grain from the drying process, the amount of grain entering and leaving this part of the system could be measured. For example, grain may be weighed before and after sun drying, and the difference would be the loss due to spillage, scattering, removal by birds, wind, etc. It is important to remember that drying losses do not include changes in moisture content, so the grain weights before and after drying should be adjusted to standard moisture content (14%). Refer to Appendix Table 3 for conversion factors.

Losses during transport

Losses during transport at the farm level may occur in moving the harvested produce (a) from the field to the threshing floor and (b) from threshing floor to the storage. Losses can also occur at the off-farm level, for example during transportation from storage to the market.

The measurement of losses during transport requires careful collection of scattered grain or weighing of grain bags at the two geographical ends of the transport process. Weighing at start and finish is likely to be the easier option, provided accurate scales and labor are available. If transport is relatively rapid, e.g., done within a 24-hour period, then no adjustments for moisture content change are likely to be needed. Otherwise, weights before and after transport should be adjusted to a standard moisture content of 14%.

Losses are normally estimated as the difference in weight between the quantities loaded (weigh-in) and unloaded (weight-out). The following information must therefore be collected:

- The quantity of grain initially loaded onto the means of transport, e.g., vehicle, pack animals, or human (weigh-in);
- The quantity of grain unloaded, having reached the dropping point (weight-out).

For long transport operations taking several days or more, the moisture content also needs to be measured at the loading and unloading points, so that appropriate corrections for changes in moisture content can be made. Grain can also suffer damage due to pest infestation, as it usually does during any storage period. To assess qualitative losses during transit, samples of grain can be taken at the loading and unloading stages and analyzed. The quantitative losses due to pest infestation should be properly captured by the weigh-in and weigh-out method. As this is a tedious process, survey designers must decide if these losses are significant enough (for example, from prior assessments) to justify the effort and expenses put into data collection.

Storage losses

The estimation of storage losses through physical measurements involves periodic visits to the farm's storage facility and the collection of grain samples and analysis of the grain samples in a laboratory. In some cases, once enumerators have collected the grain samples, they can also use visual scales to derive percentage losses while in the field. The enumerator should take advantage of each visit to assess the farm's grain stocks by asking the farmer how much of the targeted commodity is currently stored, how much was consumed since the last visit, how much was sold, and how much was added to the stock (from gifts or purchases, for example). Losses in storage can be assessed using any of the four commonly used methods, namely gravimetric, volumetric (bulk density or standard weight), TGM, and converted percentage damage methods. However, most studies have recommended the use of C&W, as well as TGM. It is very important to mention the methodology used during the assessment so that readers can have clear understanding.

Losses due to insects

There are several methods developed for measurement of losses during storage. Details are very well explained under each method in section 4.1. However, most studies have suggested that the use of C&W and TGM are more appropriate. Therefore, readers are advised to refer to those methods.

Losses due to micro-organisms (molds)

Grains infected by micro-organisms lose weight at a rate that varies according to the grain moisture content, temperature, and the amount of physical damage to the grain. There appears to be minimal research on the quantification of losses stemming from molds at the farm level. The methods used to assess weight losses caused by insects can be used for assessing losses caused by micro-organisms. The loss in weight caused by micro-organisms in a sample of grain can be calculated by comparing the damaged (infected) sample with a baseline (undamaged) sample. When contamination with mold is heavier, then it may result in complete rejection, and hence weight loss could be severe. If grains are consumable, both the qualitative and quantitative losses need to be considered. As in the case of insect loss assessments, the baseline sample should ideally be collected at the time the grain is stored. The RALT provides greater emphasis on aflatoxin detection. In such cases, samples are sent to the laboratory for reliable detection and identification. The only limitation in this recommendation is ready availability of facilities (kits), cost, and time to conduct the identification of the aflatoxin-producing fungi.

Losses due to vertebrate pests (rodents and birds)

Data, appropriate studies, and techniques to assess losses caused by rodents and birds in the literature are lacking. There have been proposals that in order to measure loss of grain cobs or heads caused by rodents, an estimate of the percentage of grain removed needs to be calculated first; second, undamaged cobs or heads of the same size as the damaged ones should be shelled or threshed and the grain weighed; last, the loss is calculated by multiplying the weight by the percentage of grain removed. It is not clear, however, how this method should be used.

In the literature, it has been proposed that losses of threshed grain to rodents can be estimated by comparing the weight of grain stored with the weight of grain removed, provided that allowance is made for other losses such as those caused by insects. This can be really challenging within farm-level studies because of the difficulty of monitoring grain movements in and out of farm storage.

Calculating total storage losses

To conduct assessments of total storage losses at the farm level, losses calculated from samples should be related to the quantity of grains originally stored and to the pattern of grain consumption.

When grain is being removed at regular intervals during the storage season, total loss caused by insects can be gauged by calculating the loss in each quantity of grain removed by comparing samples of grain that has been removed with a sample of grain collected at the beginning of the season. Boxall (1986) gives an example, which is shown in Appendix Table 2.

Losses during processing

Processing losses can happen on or off the farm, depending on the structure of the value chain, and can be the result of a manual processes (for example, hand-pounding) or mechanical processes (such as milling using hulling machines). Several processing operations can be carried out, depending on the crop and the practices. Typical operations involve de-husking, milling, and grinding of grains. At this stage, grain loss is normally expressed as a reduction in the quality of the finished product, although there may be some physical loss of grain through spillage. Losses due to scattering and spilling during processing stages can be measured by collecting and weighing the grains remaining on the ground. These losses are more significant for manual or mechanical processing at farm or village level than in specialized off-farm processing units.

At large-scale commercial mills, grain is usually processed in a continuous operation; grain can also be processed in small batches, such as by hand pounding using mortar and pestle (locally called "*muqecha*"), or using stone mills or village custom mills. Loss assessment studies at the farm level are mostly concerned with the latter mode of processing. In that case, it should be possible to weigh the grain before processing and after to obtain a measure of physical loss. In addition, a comparison between the products of the process with that of a sample of grain carefully processed in a laboratory provides an indication of the loss of quality.

Assessing losses occurring during processing is a complex and time-consuming operation. To contain survey and study costs, loss assessments at the processing stage could focus on the storage phase in processing units and exclude the losses incurred during milling, etc. Another reason for excluding such losses is that when grains are processed into flour or other products, this process is no longer part of the grain value chain in strict terms, but rather of the value chain of another product (flour, etc.) (GSARS, 2018).

Losses during packaging
Losses occurring due to defects in the methods of packaging and handling of grains can also be estimated. Data on different types of packaging could be collected for a selected sample of farmers to study the efficiency of the methods of packaging. However, within the context of the postharvest value chain, losses at this stage do not seem important. As most farmers fill their packaging material (bags) on the threshing floor, this stage is normally excluded to avoid double counting. Losses associated with packaging of grains for market are rarely considered important and are difficult to measure.

Assessment of loss during wholesale and retail
Assessing losses of grains at sites where retailers, wholesaler farmers' groups, and cooperatives, etc. aggregate their grains, in market stores and in large-scale stores, can be challenging. The sources of losses are usually two-fold, grain discarded due to sorting/conditioning, and grain loss due to bio-deterioration from insects, water leakage into the store, and, in open markets, consumption by birds, domestic animals, rodents, etc.

Grain sorting and conditioning is undertaken in order to raise grain quality to a standard at which it can be marketed. This can result in a considerable loss, since the grain that is removed in this process is often not fit for human consumption or is sold at a reduced price. Although the damage to this grain will have accrued at earlier stages in the postharvest chain, the actual weight loss is realized at this stage. The loss can be measured by following grain in the system and first measuring the gross weights of grain entering the system and then measuring the weight of good grain that comes out. For example, this could be done by following specific bags of grain submitted to the system by a particular farmer and observing how much remains after conditioning. Additional grain drying is often part of the conditioning process, so correction of weights to standard moisture content (14%) is important.

To obtain a measure of loss due to bio-deterioration, it is necessary to make an assessment of the grain soon after arrival at the store. If possible, samples should be taken from grain bags as they enter the store. The sample should be taken with a grain sampling spear. Then, the condition of the grain can be determined using a visual scale. The grain will be sampled again at appropriate intervals (not more than monthly) and samples taken at random from the accessible outer layers of bags. Changes in grain condition are monitored using a visual scale, but these will not be the only losses. A careful watch has to be kept on the grain that is discarded. This may be the sweeping of spilt grain (which in a well-run store would be carefully reconditioned and returned to a sack set aside for the purpose) or grain that has been damaged for one reason or another, especially water leaking from the roof. However, such sources of loss are likely to be small compared with the general change in grain quality over time.

5.5 Summary loss matrix

From the implementation of a well-planned assessment using key informant interviews, a key expert roundtable, sampling/load tracking, and validation at different postharvest stages (also called "postharvest profiles" by APHLIS), reliable information pertaining to extent, types, and causes of PHL can be documented. PHL assessment of any scale requires sound data collection, validation, cleaning, tabulation, and analysis.

Based on the findings of the field research conducted as survey and sampling (load tracking), the results need to be summarized. Equally important is differentiating qualitative and quantitative losses. At this stage, both CLPs and low loss points (LLPs) are identified, and the survey method should verify if the CLPs anticipated by the screening method (desktop study) indeed are CLPs.

LLP: The survey and sampling methods may reveal points in the FSC where the losses are actually unexpectedly low, which is < 1%. It is very important to record such observations and report on the reasons, as it may be the result of good practices and/or conditions that could serve as solutions to high losses in other FSCs.

For the environmental impact of food loss, it is very important to observe and record the destination of food loss: what happens with the food that is not going to be eaten by people. This food loss could be used as animal feed, as compost, put on agricultural land, or dumped as garbage. Based on these records, measures could be designed to make use of food that is lost, with minimum environmental implications.

As output of the loss assessment at different stages, we need to ***summarize*** our data in a table showing the extent, types, and causes of PHL and its impact.

5.6 Solution finding (synthesis)

The causes of food loss

This step has received much emphasis in the FAO methodology. While sometimes it is easy to determine the cause for the damage, there are often cases in which the actual cause is not as clearly identifiable. The origin of some causes could be located at the up-stream levels of the value chain, but the impact and actual losses happen further down in the value chain—or the other way around! We categorize the causes into micro (each stage of the FSC), meso (structural/secondary causes), and macro (impact of law and regulation) levels. Accordingly, the solutions could be developed at these three levels based on the identified causes supported by the actors and stakeholders who are operational and responsible at these respective levels.

A process of verification and identification of cause(s) of losses should be followed. The evaluator should describe in detail the symptoms, determine the type of defect, consult different sources about what the main factor for quality degradation was, and verify if there is more than one origin for the defects.

The solutions to food losses

PHL assessment is primarily required to produce information needed for loss reduction investment. Equally important is the identification of feasible solutions for loss reduction. FSC actors will be the first source to suggest solutions for food losses, during the survey stage. It is important to ensure women take part in solution finding. A summary of the critical losses that have been identified, including the cause(s) and potential solution(s), will be essential.

For all potential solutions suggested, interventions are proposed. However, the technical and financial (economic, commercial) feasibility of the interventions have to be determined. The cost of the intervention could be private (equipment, training, packaging) or public (infrastructure, tax benefits, credit facilities), or both. The economic feasibility should be based on at least 10 years of operation of the proposed improvements. FAO (2015) methodology has established a method to calculate a quick budget for food loss reduction intervention.

Strategies for food loss reduction

In principle, there will not be a stand-alone food loss reduction strategy, but rather strategic elements should be integrated in existing national strategies for food security, agriculture and livestock resources, and/or economic development.

A national stakeholder workshop needs to be organized at the end of the field work, to discuss and validate the proposed solutions and define elements of a food loss reduction strategy. During the workshop, the basic concepts should be prepared for an investment project to formulate the food loss reduction strategic elements in detail, apply them to the national strategies, and implement solutions to effectively reduce food losses.

CONCLUSION AND RECOMMENDATIONS

It is important to have reliable and consolidated information on the extent and causes of postharvest losses for effective planning and implementation of loss reduction interventions. There is inadequate postharvest research conducted in Ethiopia, and many of the limited studies are focused on storage-related losses in selected pocket areas. Few recent studies follow the concept of a supply chain-based approach. While the methodology used for storage studies are designed experiments, most postharvest loss assessments strongly rely on rapid appraisal techniques through focus group discussions and key informant interviews, often collecting data based on farmers' perceptions. The range of figures for postharvest losses reported by various authors for different crops is great. The average total postharvest losses reported in different literatures ranged from 15.54 to 27.2%. Crop wise, the average PHLs were 8.3–21.4%, 6.2–32.9%, 9.5–27.0%, 23.0%, 11.8–25.2%, and 16.3–21.0% for maize, sorghum, wheat, barley, haricot beans, and teff, respectively. The postharvest loss estimates were too divergent and inconsistent to justify where and how much to invest in order to reduce postharvest losses. Such variations in postharvest loss estimates are attributed to, among other causes, lack of a standard loss assessment methodology.

The causes of postharvest losses reported include limited awareness, limited availability of and access to postharvest technologies, and limited attention given to postharvest research and extension, infrastructure, etc.

Global literature documents different assessment methodologies to generate data on the extent and causes of postharvest losses. The major ones include RLAT, APHLIS, and FAO methodologies. There are also other methods that are widely used for assessment of storage losses due to bio-deterioration. These are gravimetric/C&W, volumetric (bulk density or SVW), TGM, and the converted percentage damage methodologies. Other quick methods of storage loss assessments include rapid loss assessment and visual damage score (VDS) methods.

Nonetheless, PHL assessment methodologies vary with respect to the postharvest systems, cost, ease of deployment, scientific validity, social setup, etc. under which they are effective. Each of the available methods has its own weakness and strengths in coming up with more realistic estimates that can be used for effective PHL-reduction interventions. The choice of the methodology ultimately depends on the target at which losses should be measured, characteristics of the target population, availability of human and financial resources for the study, desires of the country (which crop, what stage, frequency, etc.), and the desired properties of the postharvest loss indicators.

The present study has proposed a customized methodology for postharvest loss assessment of grains in Ethiopia by collating best aspects from already proven methodologies to come up with a more appropriate way of determining the extent, type, and causes of postharvest losses to provide pertinent information for decision-making in implementing postharvest prevention and reduction strategies. The methodology should be convenient, in order to enable postharvest loss assessments along the different functional stages of major crop value chains.

It is suggested that the customized methodology should be subjected to trial testing so that all necessary improvements are made in order to fine tune it and make it more practical and cost effective in serving its intended purpose of generating information that can provide essential justification and motivation for introducing measures designed to prevent and reduce postharvest losses of grains. While still deploying all effective loss-reduction strategies, it is recommended that future postharvest loss studies follow standardized and proven methodologies for our country.

Appreciating the good intention of this work in reviewing and compiling studies pertaining to postharvest losses in grain crops, loss reduction management options, and ultimately customization of an appropriate loss assessment methodology for Ethiopia, it remains so important to put into action a similar effort for horticultural crops, which are known to be more subject to greater postharvest losses.

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APPENDIX TABLES

Appendix Table 1. Indigenous and introduced postharvest protection measures commonly practiced by farmers in Ethiopia

S. No.	Practices
1	Admixing grain with wood ash
2	Rubbing grain with wood ash
4	Mixing grain with teff or finger millet
5	Smoking *gotera* and *gotta* with pepper
6	Rubbing *gotta* with leaves of eucalyptus
7	Applying pepper powder on stored grains
8	Direct placement of leaves of insecticidal plants on stored grains
9	Treating/fumigating with insecticides such as malathion, Phostoxin, or Actellic
10	Plastering storage structures with cow dung/soil-straw mix
11	Construction of storage structures well raised above the ground
12	Placing rolled leaves of "*chew*" (a climber plant) on the grain in storage
13	Placing white wood ash at the bottom of the storage structure
14	Allowing crops to dry in the field to safe moisture content before harvesting
15	Sorting crops into different quality grades (high, medium, and low) before storage
16	Placing storage structures in cool and ventilated area
17	Use of underground pit storage
18	Cleaning storage structures before storing new grains
19	Changing or renovating storage structures as necessary
20	Immediate sale after harvest
21	Using hermetic plastic bags, like PICS bags, cocoons (GrainPro hermetic storage), super grain bags, or triple bags, metal silos, etc.
22	Applying cattle urine to grains
23	Constructing rat baffles on the feet of raised storage structures
24	Hanging maize cobs or sorghum heads over smoke/fireplace (for seed use)
25	Keeping sorghum in the form of flour
26	Sunning, aerating, and cleaning infested grain
27	Hanging harvested crop on trees outside
28	Storing the fresh grain separately from the old grain
29	Cooling grain before putting it in the store
30	Storage of grains meant for seed purpose in gourds or *dibignit* (*gushgush*)
31	Warming grain on clay pan over fire
32	Fumigating storage containers with hot pepper
33	Tying together husks at the tip of cobs for complete coverage to prevent insects
34	Spreading infested grain in the sun to drive off insects
35	Mixing hybrid maize grain with grain of local maize variety
36	Opening grain stores less frequently to withdraw grain
37	Storing shelled maize rather than storing on the cob

Source: Tadesse et al. (2008), Tadesse and Regassa (2013), FAO (2017, unpublished)

Appendix Table 2. Grain PHL calculation during six months' storage where grain is withdrawn for use

	Months during which grain is removed					
	1	**2**	**3**	**4**	**5**	**6**
Quantity (volume) of grain removed (%)	10	10	15	15	20	30
Weight loss in sample (%)	1	2	3	5	7	10
Weight loss (as percentage of total stored)	0.1	0.2	0.45	0.75	1.4	3.0
Cumulative weight loss (as percentage of total stored)	0.1	0.3	0.75	1.5	2.9	5.9

Source: (Boxall, 1986)

Appendix Table 3. Conversion factors to obtain cereal grain weights at 14% moisture content (MC) (Multiply by)*

Moisture content %	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
8	1.0698	1.0686	1.0674	1.0663	1.0651	1.0640	1.0628	1.0616	1.0605	1.0593
9	1.0581	1.0570	1.0558	1.0547	1.0535	1.0523	1.0512	1.0500	1.0488	1.0477
10	1.0465	1.0453	1.0442	1.0430	1.0419	1.0407	1.0395	1.0384	1.0372	1.0361
11	1.0349	1.0337	1.0326	1.0314	1.0302	1.0291	1.0279	1.0267	1.0256	1.0244
12	1.0233	1.0221	1.0209	1.0198	1.0186	1.0174	1.0163	1.0151	1.0140	1.0128
13	1.0116	1.0105	1.0093	1.0081	1.0070	1.0058	1.0047	1.0034	1.0023	1.0012
14	1.0000	0.9988	0.9977	0.9965	0.9953	0.9942	0.9930	0.9919	0.9907	0.9895
15	0.9884	0.9872	0.9860	0.9849	0.9837	0.9826	0.9814	0.9802	0.9791	0.9779
16	0.9767	0.9756	0.9744	0.9733	0.9721	0.9709	0.9698	0.9686	0.9674	0.9663
17	0.9651	0.9641	0.9628	0.9616	0.9605	0.9593	0.9581	0.9569	0.9558	0.9547
18	0.9535	0.9523	0.9512	0.9500	0.9488	0.9477	0.9464	0.9452	0.9442	0.9430
19	0.9419	0.9408	0.9395	0.9384	0.9372	0.9360	0.9349	0.9337	0.9326	0.9314
20	0.9302	0.9291	0.9279	0.9267	0.9256	0.9244	0.9233	0.9221	0.9209	0.9198
21	0.9189	0.9174	0.9163	0.9151	0.9140	0.9118	0.9116	0.9105	0.9093	0.9081
22	0.9070	0.9058	0.9047	0.9035	0.9023	0.9012	0.9000	0.8988	0.8977	0.8965
23	0.8953	0.8942	0.8930	0.8919	0.8907	0.8895	0.8884	0.8872	0.8860	0.8849
24	0.8837	0.8826	0.8814	0.8802	0.8791	0.8779	0.8767	0.8766	0.8744	0.8733
25	0.8721	0.8709	0.8698	0.8686	0.8674	0.8663	0.8651	0.8640	0.8626	0.8616
26	0.8605	0.8593	0.8581	0.8570	0.8558	0.8547	0.8535	0.8523	0.8512	0.8500
27	0.8488	0.8477	0.8465	0.8453	0.8442	0.8430	0.8414	0.8407	0.8395	0.8384
28	0.8372	0.8360	0.8349	0.8337	0.8326	0.8314	0.8302	0.8291	0.8279	0.8267
29	0.8256	0.8244	0.8233	0.8221	0.8209	0.8198	0.8186	0.8174	0.8163	0.8151
30	0.8140	0.8128	0.8116	0.8105	0.8093	0.8081	0.8070	0.8058	0.8047	0.8035
31	0.8023	0.8012	0.8000	0.7988	0.7977	0.7665	0.7953	0.7942	0.7930	0.7919
32	0.7903	0.7895	0.7884	0.7872	0.7860	0.7849	0.7837	0.7826	0.7814	0.7802

Source: Toquero (1981), cited in Hodges (2013).

Appendix Table 4. Conversion factors for selected crops

Grain	Conversion factor
Maize (stored as shelled or as cobs without husks)	% bored grain/8
Maize (stored as cobs in husk)	% bored grain/4.5
Wheat	% bored grain/2
Sorghum	% bored grain/4
Paddy rice	% bored grain/2

Source: Adams and Schulten (1978).

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