Understanding smallholder's productivity by measuring food losses, soil perception and soil variability

LUCIANA DELGADO OTERO

Propositions

1. Losses in food quantity are negligible compared to losses in food quality. (This thesis)
2. Most of food losses occur pre-harvest. (This thesis)
3. Ecological conditions determine the success of agricultural interventions.
4. Sustainability requires agro-ecological specific biotechnology.
5. Digital technologies are essential to link smallholder to markets.
6. A healthy environment is impossible without healthy diets.

Propositions belonging to the thesis, entitled

"Understanding smallholder's productivity by measuring food losses, soil perception and soil variability"

Luciana Delgado Otero

Wageningen, 15 February 2022

Understanding smallholder's productivity by measuring food losses, soil perception and soil variability

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Understanding smallholder's productivity by measuring food losses, soil perception and soil variability

Luciana Delgado Otero

Thesis

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at Wageningen University

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Prof. Dr A.P.J. Mol

In the presence of the

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Chapter 1

General introduction

1.1 Problem Statement

Agri-food systems must be transformed to provide enough quantity of healthy food for everyone in a sustainable way while dealing with the dynamics of (local and global) economies and the environment. Transforming these systems requires a combination of research, policies and investments to manage complex trade-offs.

Within this context, reducing food loss and waste is widely seen as an important way to reduce production costs and increase the efficiency of food systems (FAO, 2019). Since the United Nations have made halving, food loss and food waste a Sustainable Development Goals target (UN, 2015), the topic of food loss and waste has captured the public imagination, and its significance to the development community is growing every day (FAO, 2019 and Delgado et.al 2020). Food losses measured through the Food Loss Index (FLI) of FAO (FAO, 2019) refer to the estimated 14% of food produced globally (FAO, 2019) that is lost along the distribution chain from harvest to market. Food loss measured in the FLI is valued at 400 billion US dollars per year; not only that; the food lost is associated with around 1.5 gigatonnes of CO2 equivalent, 203 billion cubic meters of surface and groundwater (blue water), and 899 million of hectares, equal to around 20% of the world's agricultural land. From a nutritional point of view, this is equivalent to more than 1,000 trillion milligrams of phosphorus and more than 350 trillion milligrams of magnesium. [1] In addition, UNEP (2021) has measured that food waste is 17% of all food produced. This is additional 931 million tonnes of food waste was generated in 2019, 61 percent of which came from households, 26 percent from food service, and 13 percent from retail.

Clearly, the magnitude of impacts in these different policy-relevant dimensions is a call to action. However, linkages between food loss and waste, on the one hand, and food security and environmental impacts, on the other, are complex and need to be thoroughly understood. Positive outcomes from reducing food losses

[1] These estimates are based on data used to produce FAO's newly developed Food Loss Index in SOFA (2019), extrapolating the impacts to include commodities that are not included specifically in the FLI commodity groups, but are represented by the groupings. These estimates are lower bounds because pre-harvest and harvest losses are not included in the FLI estimate.

and waste are far from guaranteed, and the impacts will differ according to where food loss is reduced (FAO, 2019; Cattaneo et al., 2020).

However, when looking close into the food loss and waste problem important challenges are found. First, most of the literature refers to the terms 'Post-Harvest Losses' (PHL), 'Food Loss' (FL), 'Food Waste' (FW), and 'Food Loss and Waste' (FLW) interchangeably, but they hardly ever refer consistently to the same concept. For some authors, the distinction is linked to the stages at which losses occur. For others, the distinction is based on the cause of the food loss and whether it was intentional. Recent publications (FAO, 2014; HLPE, 2014; Lipinski et al., 2013. and FAO, 2019) have tried to clarify this by defining FL as unintentional reductions in food quantity or quality before consumption. These losses usually occur in the earlier stages of the food value chain, between production and distribution, but they also occur during the wholesale and retail stages. PHL is an element of FL and excludes losses at the production level, although losses during harvest are sometimes misleadingly included in the concept (e.g., Affognon, 2014; APHLIS, 2014). The FLW concept encompasses the totality of losses and waste along the value chain with respect to total harvested production (FAO, 2014). However, this definition does not include crops lost before harvest because of pests and diseases or crops left in the field, crops lost due to poor harvesting techniques or sharp price drops, or food that was not produced because of a lack of adequate agricultural inputs, including labor availability and fertilizer. SDG 12.3.1 refers to losses from on-farm post-harvest up to processing and packaging, including wholesale.

With the objective of resolving this challenge and of having a clear, consistent definition targeting producers, in this dissertation, we will focus only on food losses, and we will follow the definition of SDG 12.3.1. i.e., looking at food losses across the value chain from o- farm up to wholesale market included.

Policies to reverse this situation have mainly aimed at increasing agricultural yields and productivity, but these efforts are often cost- and time-intensive. In addition, the loss of marketable food can reduce producers' income and increase consumers' expenses, likely having larger impacts on disadvantaged segments of the population. Therefore, this dissertation focuses on food losses as a way to increase the productivity of smallholder farmers and accelerate the process of agri-food system transformation.

To implement a strategy to reduce and prevent food loss, there are three important aspects that need to be taken into consideration. First, there is no accurate information on the extent of the problem, especially in low- and middle-income countries. For the most part, calculations of food loss hinge upon accounting exercises that use aggregate data from food balance sheets provided by national or local authorities. This macro-approach estimates, however, are often subject to large measurement error, frequently rely on poor quality data, particularly in low- and middle-income countries, and are not based on representative samples for specific stages of the value chain. Gustavson et al. (2011), Kummu et al. (2012) and Lipinski et al. (2013) used the Food Balance Sheets from FAOSTAT (2019) to estimate global food losses. More recently applied micro approaches use sample survey data regarding specific value chain actors to overcome shortcomings of the macro approach. However, these micro approaches are costly and time-consuming to implement. In addition, it can be difficult to get a large enough proportion of responses to represent an entire value chain or region across several years. Results are also hard to compare.

Second, there is only scarce evidence regarding the source or cause of food loss. Because of the aggregate nature of their data, macro studies are unable to capture the critical stages at which food loss occurs. Most micro studies capture total food loss based on producers' self-reported estimates but do not capture detailed information regarding the relative amounts of food loss incurred by different sources.

Third, there is little evidence regarding how to reduce the losses effectively. There have been efforts to introduce particular technologies along specific stages of the value chain (e.g., silos for grain storage, triple bagging for cowpea storage, or mechanized harvesting and cleaning equipment for wheat and maize).[2] However,

[2] Chatterjee (2018) looks into the impact of storage infrastructure on agricultural yield by using the subsidy program given for construction and renovation of rural godowns in India. The author finds that this subsidy program for better storage infrastructure led to an increase in the rice yield by 0.3 tons per hectare — a 20 percent increase from the

little is known about the adoption rates of these efforts, the economic sustainability, and effective policy designs, especially in low-income contexts.

Moreover, when focusing on losses, little is known about what causes food loss in developing countries and how best to reduce them (Stathers et al., 2020). It would be too simplistic to blame it on the carelessness of producers or vendors in the pre- or post-harvest handling of produce. Food loss can occur at different nodes of the value chain: production, harvest, or post-harvest stages, involving storage, transport, handling, or processing. Gaining insight into the causes of food loss (FL) can help develop the right interventions. Even though it would be impossible to completely eliminate food loss, experts agree that there is room for reducing food loss and waste. A review of the evidence suggests a wide range of possible causes, categorized into six groups: levels of human capital (education, experience); climatic conditions, insects or pest attacks; access to infrastructure and post-harvest infrastructure (especially storage facilities); access to technology, post-harvest crop management techniques and handling; economic incentives (standards); market access (mainly roads to markets). In practice, multiple factors are at play and reinforce one another.

The distribution of loss along the food chain is different depending on the commodity and the geographical location in question, but food loss and waste are commonly the result of underlying inefficient, unequal, and unsustainable food systems. Food losses occur at different stages of the food value chain (VC): production, post-production procedures, processing, distribution (FAO, 2011; HLPE, 2014; Lipinski et al., 2013).

Policies to address food insecurity or the increasing pressure on the world's available land due to growing populations and changing diets have aimed mainly at increasing agricultural yields and productivity and not focus on reduction of losses which by default will increase farmers productivity. These efforts are often cost- and time-intensive and do not consider food loss and waste reduction as a tool to help meet the growing food demand. Nor do they consider food loss reduction as a way to ease the pressure on land. Food loss also entails

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baseline. According to the author, the reduced storage costs have led to an investment in productive inputs.

unnecessary greenhouse gas emissions and excessive use of scarce resources, including land, so policies to reduce food loss will also benefit the environment (SDG's 6, 13, 14 and 15) among others (see figure 1.1). In this dissertation, it is clearly hypothesized that cutting food loss can help disadvantaged segments of the population, as the loss of marketable food can reduce producers' income and increase consumers' expenses and will be therefore only a means to increase the productivity of smallholder farmers substantially but at the same time reduce trade-offs on natural resources and environment.

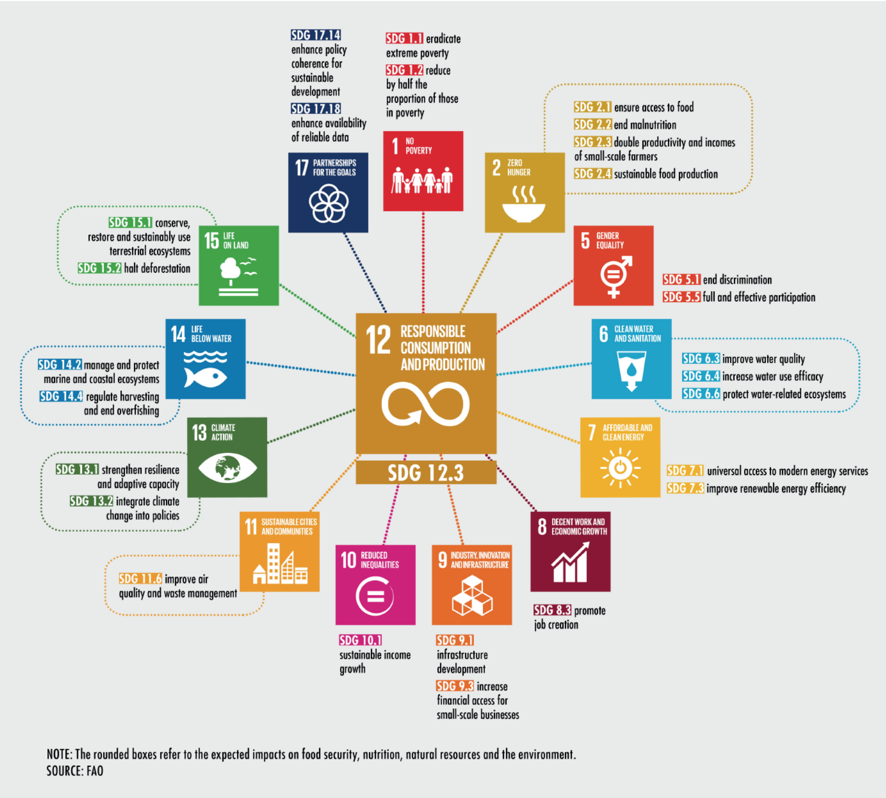

Figure 1.1: Food loss and waste and the sustainable development goals from FAO, 2019

1.2 Scope of this thesis

This dissertation tries to close the literature gap in four major areas: First, the importance of a clear definition of food losses. An effort is made to bring a detailed definition consistent with the existing official SDG definition. Second, it addresses the existing measurement gap of losses by developing and testing three new methodologies and one traditional methodology- that aims to reduce measurement error and assess the magnitude, causes and costs of food loss, as well as the stages across the value chain where losses occur. The methodology includes the measurement across the value chain and decomposes food losses at pre-harvest, left in the field, harvest and post-harvest, and includes measurement of both quantity loss and quality deterioration. In addition, it allows identifying where in the value chain the losses occur. Third, it analyzes in detail the determinants of food losses.

Finally, an additional effort is made to try to understand what the reasons are why smallholders have such a low level of adoption of technological packages or even if they adopt why the solutions are not necessarily resolving the problems they need to resolve on food losses.

The literature is clear in that there is a general problem of low adoption of interventions in agriculture (Hermans et al., 2021). The low adoption rate has been widely studied in the literature and different reasons have been identified and these include a) farmer characteristics (i.e. age, training, and social capital); b) plot characteristics (i.e. quality of the land matter; sloped); c) behavioral characteristics of the farmers (i.e. their level of risk aversion, intertemporal discount rates, and time preferences); d) access to markets and to capital and credit; e) distance to innovators or social networks; f) economic decisions made by the farmer of the allocation of their limited resources (i.e. If a farmer owns more than one field, he or she may not invest equally in each field, because of their limited natural, human, and economic capital); g) access to information and extension services. All of the previous reasons that explain adoption are more focus on existing assets (human capital and land), on access to resources but economic and social (networks, credit, markets, characteristics of the plot, and supply of extension services), and on behavioral issues (rate of risk aversion and intertemporal discount rates) but they fail to identify if the content of the adoption is what really is needed to resolve the problem at stake.

A major finding of the research is that farmer's lack of information is an important explanation. Specifically, the research focuses on one set of information on soil characteristics and conditions and identifies how the lack of appropriate information is an important determinant of the lack of adoption and effectiveness of the technological packages and therefore affecting farm productivity and increasing losses across the value chain.

1.3 Hypothesis, objectives, and research questions

The framework and structure of this dissertation is depicted in figure 1.2. The major aim is to try to understand the low levels of productivity of smallholder farmers by focusing on food losses and the low levels of technology adoption or miss-adoption of the proper solutions to the problems faced by farmers when trying to reduce losses. With this objective in mind the main aim of this research is *to understand the concept of food losses, develop new measurement methodologies, identify underlying drivers and the reasons of low adoption of new technologies.*

To reach this aim the following research questions (RQ) are at the core of the dissertation

RQ. 1. Is the mismeasurement of food losses underestimate the magnitude of losses?

RQ. 2. Are losses mostly at the post-harvest level?

RQ. 3. Is the lack of storage infrastructure the main cause of food losses at post-harvest?

RQ. 4. Did farmer's perception reflects the real need of their soils?

RQ. 5. Is policy maker's perception on soils similar to farmer's perception?

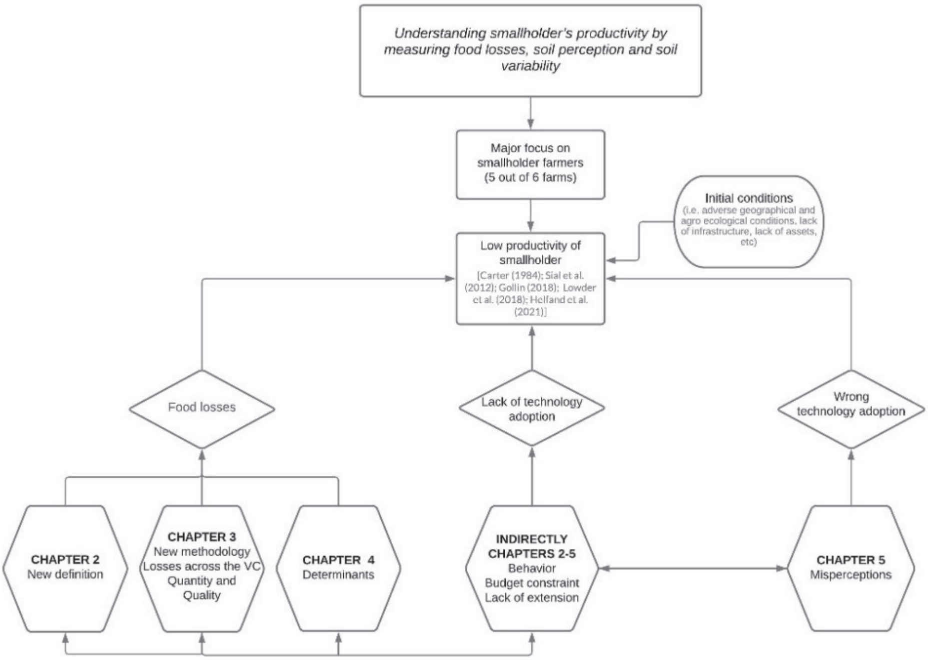

Figure 1.2: Thesis outline complemented with the main findings from each chapter

1.4 Outline

The outline of this thesis is illustrated in Figure 1.2. An attempt to answer the research questions is presented in Chapters 2 to 5 and a synthesis of the different studies is provided in chapter 6. In chapter 2, a definition on food losses is developed because most of the literature refers to the terms 'Post-Harvest Losses' (PHL), 'Food Loss' (FL), 'Food Waste' (FW), and 'Food Loss and Waste' (FLW) interchangeably, but they hardly ever refer consistently to the same concept. The definition developed is built on the definition by FAO (2014), HLPE (2014) and Lipinski et al. (2013) and expand it by including pre-harvest losses. This definition includes both quantitative losses and quality deterioration in the definition of food loss.

Chapter 3, addresses this existing measurement gap by developing and testing three new methodologies that aim to reduce measurement error and assess the magnitude, causes and costs of food loss, as well as the stages across the value chain where losses occur. The methods account for food loss from pre-harvest to product distribution and include measurement of both quantity loss and quality deterioration. Following a framework similar to the one used by de Mel et al. (2009), a benchmark is established based on observations and food loss data measured on the farm. Every effort has been made to be as detailed as possible on the attributes and categories identified in each commodity and country, and to establish consistency across the three new methodologies. This methodology is applied to producers, middlemen, and processors in seven staple food value chains in six developing countries.

For this purpose, a specially designed survey was implemented to capture food loss along five staple food value chains in seven countries: potato in Peru and Ecuador, maize and beans in Honduras and Guatemala, maize in Mozambique, teff in Ethiopia, and wheat in China. Cereal grains, such as wheat, maize, potatoes, and beans, are the world's most popular food crops and form the basis of the staple diet in most developing countries.

The surveys were tailored to specific countries, commodities, and commodity varieties (for example, while maize in Honduras and Guatemala have the same attributes, wheat in China has different attributes than wheat in Mexico), they provide a consistent measurement of food loss across different agents in the value chain (i.e., farmers, middlemen, and processors). The surveys capture detailed information about these agents' different processes and quantify food loss along each production stage by collecting self-reported measures of the volumes and values of food losses incurred during different processes (harvesting, threshing, milling, shelling, winnowing, drying, packaging, transporting, sorting, picking, transforming, etc.). In addition, losses are estimated based on commodity damage by collecting detailed data from farmers, middlemen, and processors regarding the quality (based on damage coefficients) of agricultural commodities that they use as inputs and outputs. This allowed to quantify food loss in terms of the quality attributable to each agent across the value chain.

In chapter 4, the determinants behind the losses are measured showing that some socio-economic characteristics (i.e., gender, age, education); market access, mechanization and technology in production and post-harvest activities; unfavorable climatic conditions, pests, and diseases as well as lack of adequate storage techniques, influence losses. Methodologically, we use two alternative econometric models: the model of classical maximum likelihood estimation is used to assess the relationship between variables and the binary Food loss variable; fractional response models (GLM) are used on the share of product loss to account for the boundedness of the dependent variable. The results reveal specific areas that require investments to reduce food loss and show considerable heterogeneity of food loss. The causes of food loss appear to be highly specific to context and type of commodity.

Based on the determinants of food losses analysis in chapter 4, the research hypothesizes that farmer's lack of information on soil characteristics and conditions could be one important determinant of the lack of adoption and effectiveness of the technological packages and therefore affecting farm productivity and increasing losses across the value chain.

In chapter 5, it is shown how different is the perception between "policymakers" and producers and found that farmers have perceptions that not necessarily were consistent with the soil characteristics of their plots. As a result, this lack of appropriate information on soil characteristics and conditions could be an important determinant of the lack of adoption and effectiveness of the technological packages and affecting farm productivity and increasing losses across the value chain.

This dissertation argues that understanding the real problem that needs to be resolved with the adoption of a new technology or practice is central to increasing adoption rates. Identifying the problem — specifically providing information to the farmer and policymakers so that they understand and perceive the real problem — will determine the adoption rates of intervention.

Finally, chapter 6 present the synthesis with the conclusions and policy recommendations. This chapter finds that addressing food loss across the value chain first requires a common understanding of the concept by all actors, as well as a collaborative effort to collect better micro data across different commodities and contexts. This will help to better target interventions and to identify the needed technologies, value chain infrastructure, and extension services to minimize losses. While there are commonalities, food loss is very context specific.

The heterogeneity suggests that policies aiming at the reduction and prevention of food loss need to be developed with specific commodity and context in mind. Finally, policy makers need to take into consideration the correct or incorrect perception of farmers and their packages and policies need to respond to the reality faced by the farmers and should also aim to reduce the asymmetry of information faced by some producers.

Chapter 2

Food losses: What we know and what we do not

Food loss has been defined in many ways, and disagreement remains over proper terminology and methodology to measure it. Although the terms "postharvest loss," "food loss," "food waste," and "food loss and waste" are frequently used interchangeably, they do not refer consistently to the same problem and to the same aspects of the problem. Also, none of these classifications includes pre-harvest losses, such as crops lost to pests and diseases before harvest, crops left in the field, crops lost because of poor harvesting techniques or sharp price drops, or food that was not produced because of a lack of proper agricultural inputs and technology. Consequently, and despite its presumed importance, figures on food loss are highly inconsistent and very difficult to compare them. In addition, the precise causes for food loss and where in the value chain they occur remain undetected and success stories of decreasing food loss are not many. In this paper, we do a detail literature review of what is known on measurement of food losses, in the determinants of food losses and finally on the different interventions implemented to reduce food losses across the value chain.

<u>This chapter is based on:</u>

Delgado, Luciana; Schuster, Monica; and Torero, Maximo. 2021. Food losses in food systems: What we know and what we do not. Forthcoming Annual Reviews of Economics.

2.1 Introduction

Since the United Nations have made halving food loss and food waste a Sustainable Development Goals target, the topic of food loss and food waste has captured the public imagination, and its significance to the development community is growing every day. And yet, policies to address food insecurity or the increasing pressure on the world's available land due to growing populations and changing diets have aimed mainly at increasing agricultural yields and productivity. These efforts are often cost- and time-intensive, and do not consider food loss and waste reduction as a tool to help meet the growing food demand. Nor do they consider food loss reduction as a way to ease the pressure on land. Food loss entails unnecessary greenhouse gas emissions and excessive use of scarce resources, including land, so policies to reduce food loss will also benefit the environment. Finally, cutting food loss can help disadvantaged segments of the population, as the loss of marketable food can reduce producers' income and increase consumers' expenses.

Most of the literature refers to the terms 'Post-Harvest Losses' (PHL), 'Food Loss' (FL), 'Food Waste' (FW), and 'Food Loss and Waste' (FLW) interchangeably, but they hardly ever refer consistently to the same concept. For some authors, the distinction is linked to the stages at which the loss occurs. For others, it is based on the cause of the food loss and whether it was intentional. Recent publications have tried to clarify this (FAO, 2014; HLPE, 2014; Lipinski et al., 2013. and FAO, 2019), by defining FL as unintentional reductions in food quantity or quality before consumption. These losses usually occur in the earlier stages of the food value chain, between production and distribution, but they also occur during the wholesale and retail stages. PHL is an element of FL and excludes losses at the production level, although losses during harvest are sometimes misleadingly included in the concept (e.g. Affognon, 2014; APHLIS, 2014). FW refers to food that is fit for human consumption but that is deliberately discarded. This is most common at the end of the value chain, at the retail and household level.[3] The FLW

[3] Bellemare et al. (2017) uses the food life cycle approach (which includes- grower, processor, retailer and consumer) to give a new and contrasting definition of food waste. According to this definition, food waste is the "difference between the amount of food produced and the sum of all food employed in any kind of productive use, whether it is food or non-food." On the basis of a simple theoretical relationship and numerical

concept encompasses the totality of losses and waste along the value chain with respect to total harvested production (FAO, 2014). However, this definition does not include crops lost before harvest due to pests and diseases or crops left in the field, crops lost due to poor harvesting techniques or sharp price drops, or food that was not produced because of a lack of adequate agricultural inputs, including labor availability and fertilizer.

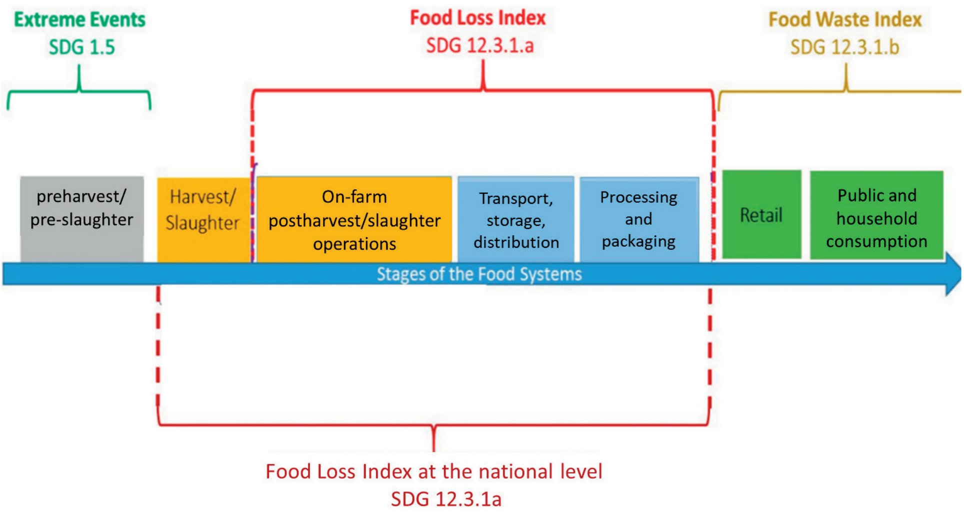

Figure 2.1: Scope of the food loss index along the food supply chain. Source: FAO (2019).

As shown in Figure 2.1, there is an official definition used to monitor progress towards the SDGs. SDG 12.3.1 defines losses from on farm post-harvest up to processing and packaging, including wholesale. Food waste happens at the retail and household level. Losses that occur pre-harvest are not considered part of food loss, even though they should be (FAO, 2019). But we can even propose a more expansive definition using a new term, 'Potential Food Loss and Waste' (PFLW) (Figure 2.2). This new definition may incorporate important pre-harvest losses stated above and also allow assessment of the relative importance of traditional ways of measuring losses (accounting methodology) with the

examples the authors explain that both quantity and the value of food waste is overstated by other definitions of FAO, EPA, ERS and FUSIONS.

opportunity cost of using the natural resources in the most efficient way and to their maximum potential.

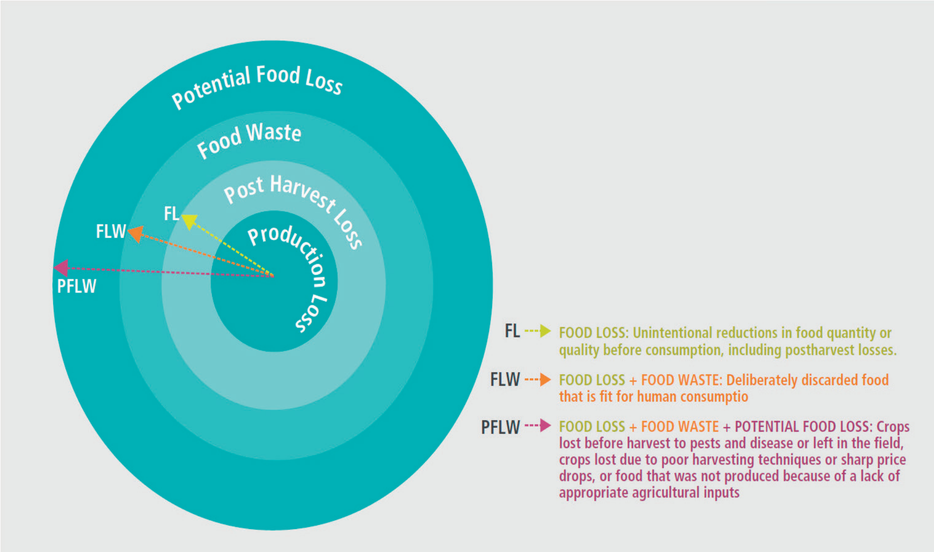

Figure 2.2: Food Loss and Waste Methodology. Source: Schuster and Torero (2016)

To capture the potential loss (PFWL), profit frontiers should be used. The two most commonly used methods to estimate the efficiency of production units are data envelopment analysis (DEA) (Charnes et al., 1978; 1981) and stochastic frontier analysis (SFA) (Aigner et al., 1977; Meussen and van den Broeck, 1977; Battese and Corra, 1977). DEA is a non-parametric approach that uses linear programming to identify the efficient frontier, while SFA is a parametric approach that hypothesizes a functional form and uses the data to econometrically estimate the parameters of that function. Both methods measure efficiency as the distance between the observed and maximum possible (frontier) outcomes. However, for the purposes of this paper, SFA is more appropriate as, unlike DEA, it allows to separate random error from the efficiency score. This feature is important when analyzing agricultural activities, as they are constantly exposed and extremely sensitive to negative and positive random shocks, such as droughts and variation in international prices. DEA estimates a deterministic frontier that incorporates the noise as part of the efficiency score, which is more appropriate when analyzing decision-making units, such as banks or factories, rather than smallholder farms in developing countries.[4]

Understanding the definitions is a first step but is also important to know how much food is lost and wasted, as well as where and why. Second, we need to be clear about the underlying objectives for reducing food loss and waste – be they related to efficiency, food security or the environment. Third, we need to understand the effectiveness of food loss and waste interventions and how much can be recycled into the food systems as a result. Fourth, we need to know the extent to which food loss and waste, and the measures to reduce it, are affecting the objectives being pursued: is there evidence on interventions and incentives that can help. A number of studies have provided insights that can help design interventions to reduce FLW. Some are conceptual (Bellemare et al., 2017; Koester, 2017; Ellison et al., 2019), while others provide more of an overview (Affognon et al., 2015; Sheahan and Barrett, 2017; Xue et al., 2017; Aragie et al., 2018; Reynolds et al., 2019) or focus on methodology and measurement (Garrone et al., 2014; Delgado et al., 2021a; FAO, 2019), as well as protocols being developed (FLW protocol, 2016).

This paper is organized as follows. Following this introduction, section 2.2 reviews the literature on how food losses have been measured and identifies the differences in definitions, which is essential when interpreting the different numbers being used. Section 2.3 presents a review of the different magnitudes of food loss and waste. Section 2.4 presents what is known about the determinants of food losses. Section 2.5 reviews the interventions that have been implemented to reduce losses and their impacts. The paper ends with conclusions and policy recommendations.

[4] The SFA approach allows the econometric exploration of the notion that the investment, production decisions and technological innovations a farmer makes or adopts translate into higher (or lower) production and income, given the fixed local agroecological and economic conditions in a micro-region and the occurrence of random shocks that affect agricultural production, such as weather and prices. In such context, inefficiency is defined as the loss incurred by operating away from the frontier, given the current prices and fixed factors faced by the household. By estimating where the frontier lies and how far each producer is from it, the stochastic frontier approach helps to identify potential and efficiency levels, therefore making it possible to calculate the PFLW.

2.2 How food losses have been measured

Two main estimation methodologies have been used to study food loss across the value chain: a macro approach, using aggregated data from national or local authorities and large companies, and a micro approach, using data specific to actors in the different value chain stages (Figure 2.3). The macro approach relies on mass or energy balances, in which raw material inputs, either by weight or in caloric terms, are compared with produce outputs. This is a low-cost method to obtain an indication of overall losses along the entire value chain and was used by Gustavsson et al. (2011) – arguably the most quoted source on the subject – and is widely used as a reference for global food loss and waste estimates. Using FAOSTAT's Food Balance Sheets, the study estimates that around 32% of global food production is lost along the entire food value chain. Kummu et al. (2012) and Lipinski et al. (2013) found, using the same raw data, that this translates into a 24% decrease in caloric terms.

In country-specific studies, macro energy balances show that 48% of the total calories produced are lost across the whole food value chain in Switzerland (Beretta et al., 2013), while mass balance data series from the U.S. Department of Agriculture, using alternative assumptions, show a loss of 28.7% of the harvested product between post-production and consumption in the United States (Venkat et al., 2011), and that 31% of the available U.S. food supply is lost during distribution and consumption (Buzby et al., 2014). A disadvantage of this method is the demand for representative and high-quality data on production, loss and waste. Data gaps are particularly serious in certain world regions, such as low- and middle-income countries, and specific stages of the value chain, such as primary production, processing, and retail (Stuart, 2009). The method is also not representative of smaller regional units, making it impossible to identify the value chain stages at which the losses occur and hampering loss reduction interventions. Finally, the aggregate data used for mass balances often cannot differentiate among natural loss (e.g. moisture loss), unnatural weight loss (e.g. due to spoilage), and edible and inedible loss.

The micro approach uses sample survey data for specific value chain actors. Data are obtained through: structured questionnaires and interviews, food loss and waste diaries compiled directly by the value-chain actor, direct measurements by the researcher, and food scanning methods, which can be used in developed retail markets. These methods are highly region- and context-specific, providing information on the origin of loss along the value chain and insights into the causes and how they can be prevented. A study by the African Postharvest Losses Information System estimates that the primary production and post-harvest weight loss for cereal crops in sub-Saharan Africa is between 14.3 and 15.8% of total production (APHLIS, 2014). Kader (2009) reviews previous estimates of losses in both developing and developed countries to find an average of 32% loss for fruits and vegetables. A study by Monier et al. (2010) quantified losses along different stages of the food value chain for 27 EU member states. Excluding waste at the agricultural production level, they arrive at an estimate of an annual average of 89 million tons of waste (179 kg per capita). A study by WRAP (2010), analyzing waste from the food and drink supply chain in the U.K., finds that 18.4 million tons of total food and drink are wasted annually across processing, distribution, and consumption stages. Households are responsible for the largest share, wasting 22% of their purchases (WRAP, 2009). According to FAO's Food Loss Index (FLI), around 14% of the world's food was lost between post-harvest and retail in 2016.

These estimates measure losses in physical quantities for different commodities and then calculate their weights to aggregate them. More valuable commodities carry a larger weight in loss estimation than low-value commodities (FAO, 2019). Delgado et al. (2021a) quantify food loss, taking into account both quality and quantity, using three new and one traditional measurement methodologies. All four methodologies can measure losses at different stages of the value chain and can be applied across crops and regions. Comparative results suggest that losses are highest at the producer level and smallest at the middleman level. Self-reported measures, frequently used in the literature, seem to consistently underestimate food losses.

The main challenges for using micro methods to estimate food loss is the cost and time to implement the studies and the challenges posed in obtaining a large amount of responses to represent an entire value chain or region. Results can be hard to compare because studies focus on specific stages of the value chain and use different data collection and estimation methodologies, depending on their objectives.

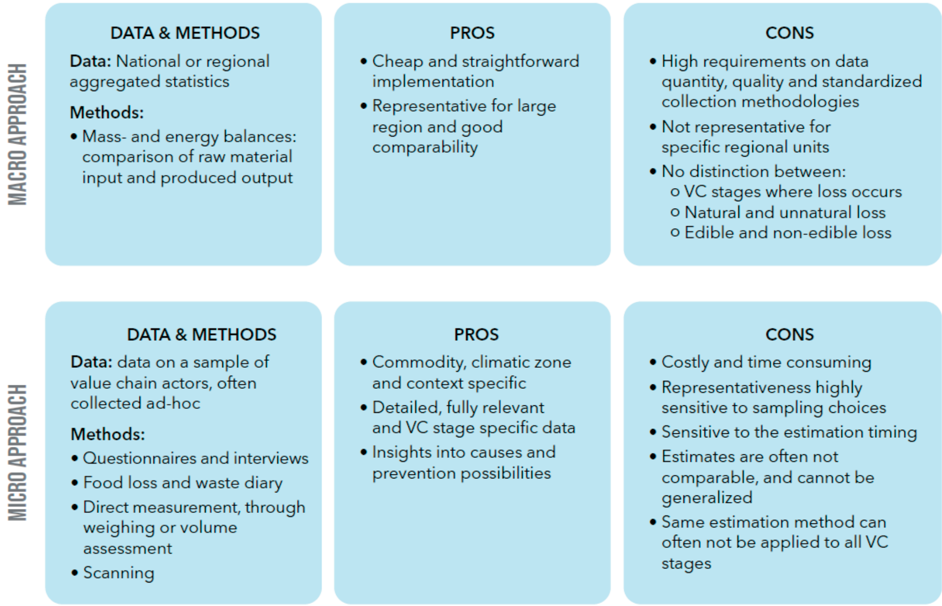

Figure 2.3: Food Losses Estimation Methodologies. Source: Delgado et al. (2021a)

Figure 2.3 summarizes the macro and micro approaches to FLW estimation, highlighting their advantages and drawbacks. A review of 213 papers on food loss and waste in sub-Saharan Africa identified large differences in estimates attributable to the choice of methodology and factors such as agro-ecological conditions, technology, and socioeconomic contexts affecting both production and post-production.[5] Sheahan and Barrett (2017), reviewing point out that there is a large gap and no clear consensus on the estimates. The authors recommend the wider adoption of a new survey method used in Asia by Minten et al. (2016). They also lament the lack of attention given to food quality losses and the paucity of research on the normal range of losses.

Standardizing estimation methods is clearly desirable. But this alone will not be enough to identify the underlying causes and potential solutions or to monitor

[5] H. Affognon et al., "Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis."

progress on reduction targets. A standard definition and terminology for food loss and waste is also essential. To be most useful, the definition should adopt a value chain approach and include pre-harvest losses. Rooted in this definition, goals for reducing food loss and waste must include both quantitative and qualitative criteria, measurable in economic, caloric, or quality-adjusted weight terms. In addition, assessments must identify loss and waste occurring at particular value chain stages, not just the overall loss. Measurement must also take into account that food loss and waste often originate at different stages along the value chain in different geographical locations.[6]

Estimation methods used for low- and middle-income countries should differ from those for high-income countries because of data availability. The methodology for developing countries should measure food reductions at different stages of the value chain and be applicable across crops and regions. Representative surveys of farmers, middlemen, wholesale buyers, and processors will provide descriptions of inputs, harvesting, storage, handling, and processing practices for each stage and help estimate product quantities, quality, and prices along the value chain.

In developed countries, detailed data on food loss and waste in the processing, distribution, wholesale, and retail stages are often tracked by private companies, but the data are not made available to researchers and policymakers. Transparency is necessary in order to systematize data collection and increase access to reliable food loss and waste information. The methodology must capture both quantitative and qualitative food loss, as well as discretionary food waste in the processing, large distribution, and retail sectors. Capturing food service waste and household waste is more challenging—data will need to be

[6] In developing countries, food loss tends to occur in the early stages of a value chain and represents a common bottleneck; in industrialized regions, food waste is widespread and results from food system decisions and consumer negligence at later stages of the value chain (FAO, Global Food Losses and Waste: Extent, Causes and Prevention; R. Hodges, Postharvest Weight Loss Estimates for Cereal Supply Calculations in East and Southern Africa (Chatham, UK: Natural Resources Institute, 2010); A. Kader, "Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce," Acta Horticulturae 682 (2005): 2169–2175; J. Parfitt et al., "Food Waste within Food Supply Chains: Quantification and Potential for Change to 2050.")

collected through representative samples using a variety of methods, such as waste composition analysis, questionnaires, interviews, or waste diaries.[7]

2.3 What we know about the magnitude of food loss and waste

One difficulty in grasping the enormity of the problem is that there is no agreement on the definition of food loss at each stage of the value chain. Losses across the value chain can originate from reductions in both food quantity and food quality and can be described in terms of weight, caloric, nutritional, and/or economic losses.

Due to estimation difficulties, product seasonality, and market sensitivity to food quality, most studies analyze the quantity of food loss in terms of weight reduction (Hodges et al., 2014; HLPE, 2014). Some studies translate quantity losses into caloric terms (e.g. Buzby et al., 2014; Kummu et al., 2012; Lipinski et al., 2013), but do not capture qualitative dimensions, such as loss of nutritional content and physical appearance (Affognon et al., 2014).[8] The choice of definition has important implications for the estimation methodology used to examine food loss and for interpreting results.

FAO had estimated in 2011 that around a third of the world's food was lost or wasted every year. This estimate is still widely cited even though it was very rough. FAO and UN Environment Program have since prepared two indices to estimate more precisely how much food is lost in production or in the supply chain before it reaches the retail level (through the Food Loss Index), and how

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[7] WRAP, Methods Used for Household Food and Drink Waste in the UK 2012, Final Report (WRAP: 2013).

[8] Affognon et al. (2014) surveys 832 published and unpublished papers on PHL research across six countries (Ghana, Benin, Kenya, Tanzania, Malawi and Mozambique) over a span of 32 years (1980-2012). They highlight five major findings: a) PHL data is poor across various stages of the value chain, regions, commodities, and the data are of poor quality; b) there is no standard measure of PHL assessment and ambiguities exist; c) loss assessment methodologies need standardization, which comprises various steps; d) most of the research focused only on the storage part for technological development — there is a need to focus on the entire value chain for innovation; e) many PHL reduction techniques are dedicated to certain parts of the value chain, but these are not well promoted.

much is subsequently wasted by consumers or retailers (through the Food Waste Index).

Although progress has been made in tracking food loss, the limited data provided by countries remain a constraint. Fabi et al. (2020) state that in the short run, the only available option is to make best use of existing information. Data owners and researchers may use common repositories of international organizations such as the World Bank, APHLIS, WRI and FAO, where information can be shared, harmonized to the extent possible, aggregated, and employed in estimation models to generate policy-relevant evidence.

A global estimate helps promote awareness and advocacy actions, as well as research to identify those regions and commodities for which the issue is most grave. But it does not provide information on the magnitude of FLW across regions, commodities, and supply chains that is essential to identify where interventions will have the greatest impact. To produce the first estimates for the FLI, FAO gathered more than 500 studies on food loss and waste and developed a detailed meta-analysis (Fabi et al., 2020).

Since estimating losses for many commodities across all countries is operationally challenging, the FLI focuses on five commodity groups for each country: 1. cereals and pulses; 2. fruits and vegetables; 3. roots, tubers and oil-bearing crops; 4. animal products; 5. fish and fish products. To keep data collection costs manageable, the FLI selects only a few critical products and continuously improves their data quality.

Units and their suitability for measuring a specific objective, such as social, economic, or environmental objectives, are an important aspect of measurement. The FLI is based on the economic value as reflected by farmgate prices of commodities, which may be relevant when devising food loss interventions as it accounts for the costs and benefits of loss reductions and incorporates quantity and quality aspects. However, food loss can be measured using a range of metrics depending on the objectives pursued (Delgado et al., 2021a). Caloric units may be more relevant in nutritional terms, in which case energy-dense foods will have a greater weight in calculating food loss. If the policy focus is on environmental sustainability, it can make sense to look at purely physical quantities, such as tons of food lost, and multiply them by an environmental impact factor.

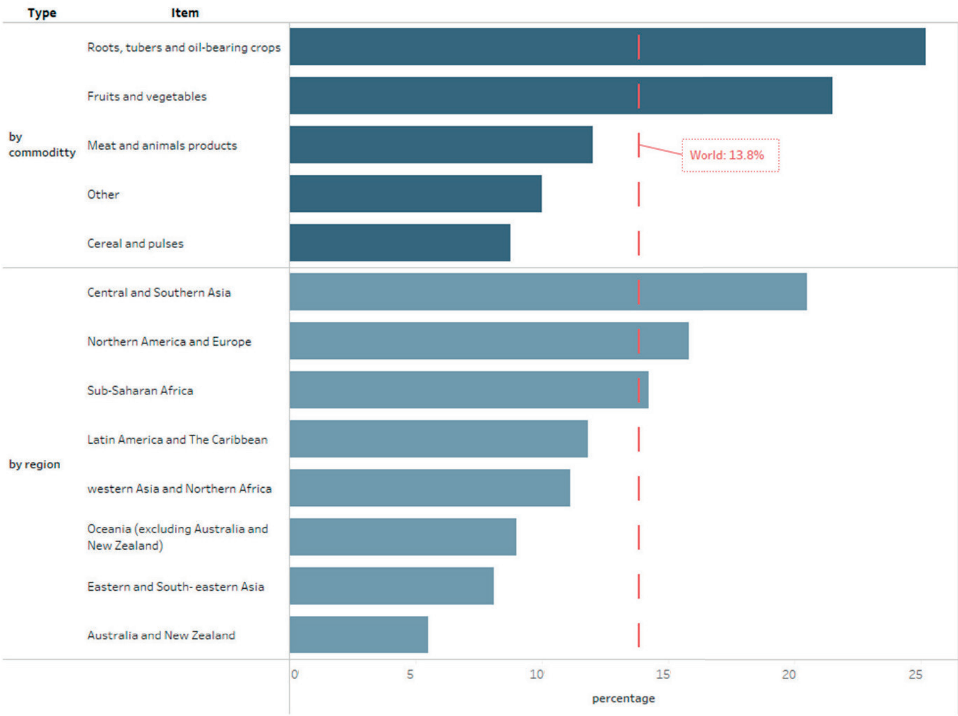

Figure 2.4. Food Losses from Postharvest to (but excluding) retail stage. Source: Author's elaboration based on FAO (2019)

Figure 2.4 shows that 13.8% of food produced globally is lost from post-harvest up to the retail level. At the regional level, estimates range from Australia and New Zealand's 5–6% to Central and Southern Asia's 20–21%. In terms of food groups, roots, tubers and oil-bearing crops report the highest level of loss, followed by fruits and vegetables (Figure 2.4). The high levels of losses for fruits and vegetables can be explained by their highly perishable nature. Results for roots, tubers and oil-bearing crops are mainly driven by cassava and potato losses. Cassava is the highly perishable and can deteriorate within two or three days. Potatoes require careful handling and proper storage, especially in the warm and humid climates of many developing countries (FAO, 1998).

Measuring post-harvest losses is an important first step toward understanding the causes of food loss. As the evidence base on postharvest loss reduction interventions is relatively sparse for most of the key staple food crops in sub-Saharan Africa and South Asia, future studies should seek to increase data for key legumes, root and tuber crops, fruits and vegetables. The limited evidence that does exist may be applied to other crops within each crop group, although field-level studies should be conducted first to confirm the validity of such an approach.

Intervention has mainly focused on tangible technical measures to reduce losses during storage for both durable crops (cereals, legumes) and perishable crops (fruits, vegetables and roots and tubers). Future studies should pursue interventions across the full value chain and the key actors, including farmers, traders, and wholesalers, with a particular focus on identifying critical loss points (Edwardson, 2018). Evidence on the effect of training, finance, policy or infrastructure interventions on post-harvest loss reduction should also be augmented.

This meta-analysis conducted by FAO (2019) and Fabi et.al (2020) is the most comprehensive study on FLW to date. It helps clarify how FLW varies across supply chains, commodity groups and regions. Figure 2.5 summarizes main results, from production through to wholesale and retail. It shows the range of percentages of food lost or wasted at the various stages of the food supply chain for cereals and pulses (Figure 2.5a) and for fruits and vegetables (Figure 2.5b), using data for Central and Southern Asia, Eastern and Southeastern Asia and sub-Saharan Africa.

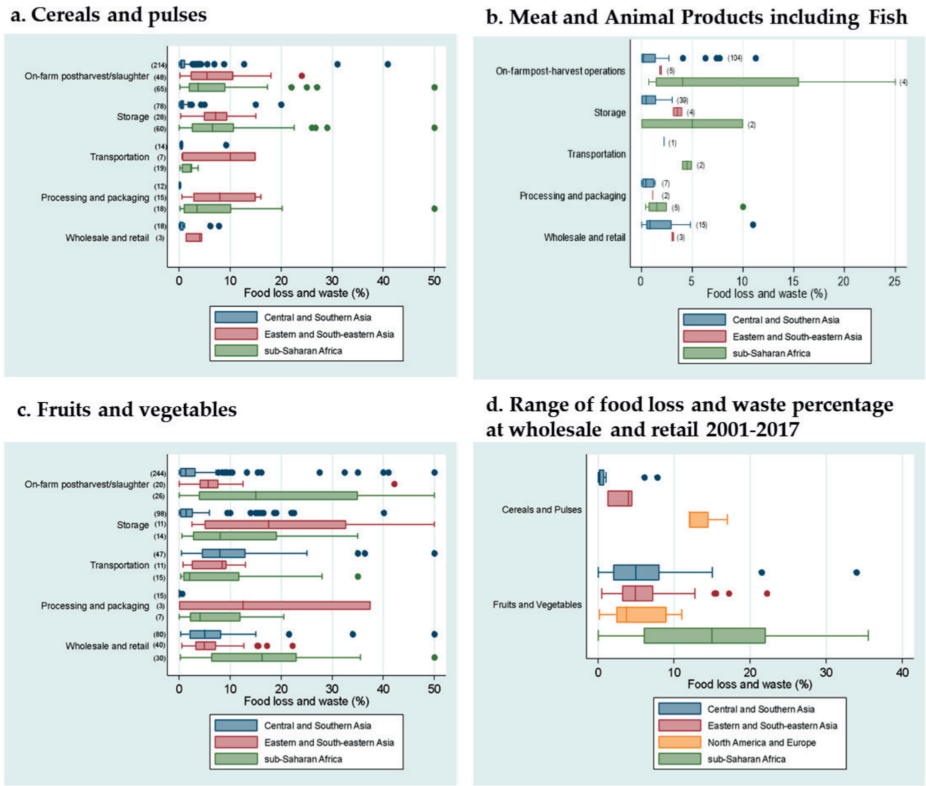

Figure 2.5. Range of reported food loss and waste percentages by supply chain stage (2000–2017) Source: FAO, 2019.

Note: *Each box contains the middle half of all data points (observations), from the 25th to the 75th percentile of observations. The vertical line inside the box shows the median observation; for half of the observations, the percentage of food lost or wasted is equal to or greater than this value, and for half of the observations it is smaller. The upper and lower whiskers contain the values up to and above the middle 50 percent (up to the 25th and above the 75th percentile, respectively) and so the end of the whiskers show the maximum (greatest value) and the minimum (least value), excluding outliers. Dots represent outliers. The number of observations is shown in parentheses. Figure 2.5a comprises 599 observations for cereals and pulses, of which 56 percent refer to Central and Southern Asia, 27 percent to sub-Saharan Africa and 17 percent to Eastern and South-eastern Asia. Most observations concern the on-farm stage (55 percent of all observations) and storage (28 percent). Figure 2.5b includes 661 observations, 73 percent of which are for Central and Southern Asia, followed by 14 percent for sub-Saharan Africa, and 13 percent for Eastern and South-eastern Asia. 44 percent of observations in Figure 2.5c concern the on-farm stage (44 percent), followed by retail (23 percent) and storage (19 percent). It is not possible to aggregate the percentages across the food supply chains due to differences in the scopes of the studies. The dates, 2000–2017, refer to when the measurements were taken, however the date of publication was used if the study dates were not available or were unclear.*

The loss values for fruits and vegetables vary greatly, indicating significant potential for loss reduction, especially in sub-Saharan Africa and Eastern and Southeastern Asia. The median levels of loss or waste in Central and Southern Asia do not exceed 10% at any stage of the supply chain; however, the considerable range of percentages indicates important potential for reduction, particularly during transportation and at the retail stage. The causes of food waste at the retail stage are linked to the limited shelf life of food products, the need for products to meet aesthetic standards and the variability of demand, particularly for fresh products. The actions and decisions of retailers as to the quality and quantity of food products dictate those of their suppliers. Conditions within retail outlets (e.g. temperature and relative humidity), the quality of packaging, and handling practices affect the quality, shelf life, and acceptability of food products. Figure 2.5d also presents loss and waste levels for fruits and vegetables, and cereals and pulses in developed regions (North America and Europe) and less developed regions. The estimates in Figure 2.5d may also capture food lost at the wholesale level; in many countries, the distinction between wholesale and retail markets is blurred. Fruits and vegetables and other highly perishable food products, such as animal products or baked and cooked foods, generally suffer higher waste at the retail stage than cereals and pulses.

Between 0 and 15% of fruits and vegetables are wasted at the retail level in all regions except sub-Saharan Africa, where waste levels reach up to 35%, suggesting a large potential for waste reduction in the region. Possible causes of the wide range of values include inadequate packaging and temperature and humidity control, especially when produce is sold under the hot sun in open-air markets, for both Asian regions, waste percentages exceed 10%; their median waste value is the same, but Central and Southern Asia demonstrates a higher variability, suggesting more scope for waste reduction. The median waste percentage for fruits and vegetables at the retail level is lowest in North America and Europe, although still significant (at 3.75%), supporting the finding that even in high income countries, retail waste levels can be high. The tendency to sell homogenous, “perfect” products in terms of color, shape and size contributes to food waste at the retail level, especially in high-income countries. Food failing to meet these standards is discarded. Processing less-than-perfect products into ready-made foods may be one way of using discarded fresh foods, but these foods spoil easily and are may be discarded or sold at a lower price, reflecting qualitative waste.[4]Likewise, highly perishable products such as fish are more likely to suffer from quality loss or be discarded if not sold quickly. In Brazil, unsold fish was sold at a 75% price decrease at the end of the first day and a further 50% after three days.

The wide ranges of values in Figure 2.5 highlight the need to measure losses and waste at each stage in the food supply chain carefully to identify the points at which they occur.

The mean and median levels of loss and waste of cereals and pulses are almost always lower than those of the more perishable fruits and vegetables. Nevertheless, the levels are still significant, indicating a need for intervention. The wide range of reported percentages — for example, in sub-Saharan Africa and Eastern and South-eastern Asia — highlights the scope for reduction. In Central and Southern Asia, by contrast, the range of the loss and waste percentages reported for cereals and pulses is extremely limited for all stages of the supply chain, indicates that countries in this region should prioritize food products other than cereals and pulses in their food loss and waste strategies.

In summary, the literature and the FLI show that losses and waste tend to be higher for specific commodity groups, although they can occur at all stages of the food supply chain to different degrees. What is striking is the vast range of percentages of food loss and waste for the same commodities and the same stages in the supply chain both within and across countries (FAO, 2019). This suggests that there is considerable potential to reduce food loss and waste where percentage losses are higher than in other places, and also that the occurrence of food loss and waste across food supply chains cannot be generalized. Critical loss points in specific supply chains must be identified as a crucial step in taking appropriate countermeasures.

2.4 What we know about causes and determinants

A review of the evidence developed by Delgado et al. (2021b) suggests a wide range of possible causes of food losses, including: production practices on soil and inputs, socio-economic characteristics of the farmer, market access (mainly roads to markets), mechanization and technology, access to infrastructure, especially storage facilities, and growing conditions (pests and disease) and climatic conditions.

Production practices on soil and inputs

Soil is essential to produce any crop in all production systems. At the most basic level it anchors the plant by providing physical support for roots and supplies the plant with essential nutrients and water (Weiland, 2012). However, soil properties and conditions constitute the environment in which plant roots interact with soil-borne insects and pathogens, influencing the occurrence and severity of plant diseases that inhibit plant growth (Ghorbani et al., 2008). Effective pest management decisions depend on a sound understanding of how soil properties and nutrients affect both plants and pests. Although there is great diversity of soil characteristics globally, a common set of basic soil properties can be identified as playing a role in soil–pest interactions (Weiland, 2012).

Plant production interventions aim to maintain and improve soil fertility and productivity through the targeted use of resources, including organic and inorganic fertilizers (Rengel, 2020; Benjamin et al., 2003). The inadequate supply of any of the 16 essential macro- and micro-nutrients in the soil reduce yields and the quality of crops produced will be compromised leading to food losses (Alloway, 2008, Reddy, 2017, Karthika et al., 2018, Rengel, 2020). All production systems have limitations imposed by natural and economic conditions. The objective of sound nutrient management is to make the best use of soil and applied nutrients according to the characteristics and demands for a specific crop and its own soil characteristics so as to obtain optimal production with minimal reduction of soil nutrient content.

Plants can be affected by a range of stresses during their growth cycle, triggered by factors relating to soil, moisture, salinity, temperature, and pests. How effectively crops withstand such stresses is strongly influenced by their nutrient status. By optimizing plant nutrition, producers can enable the crop to reduce the negative effects of the stress and minimize potential yield losses (Roy et al., 2006). The soil environment influences crop growth indirectly by affecting weed growth, pests and diseases and directly by supplying water and nutrients (Ghorbani et al., 2008).

Knowing the characteristics of your location, with its associated soil properties, is a determining factor in identifying the most appropriate disease and pest management practices (Weiland, 2012). While the general principles are well understood in theory, more detailed knowledge is needed about soil factors and soil environmental conditions that influence the severity of plant diseases (Ghorbani et al., 2008). Some properties, such as soil texture, are relatively fixed; others, however, can be influenced through appropriate management practices to benefit plant health over that of pests and pathogens (Weiland, 2012).

Soil texture and structure are the most important properties in soil–pest relationships because they directly affect other soil characteristics that are crucial for plant growth, such as water-holding capacity, nutrient availability, gas exchange, root growth and soil moisture level (Ghorbani et al., 2008). For example, stem rot (*Rhizoctonia solani*) incidence in cauliflower was reported to be higher in sandy soils than in clayey soils (Chauhan et al., 2000a, b), and incidence of the soft rot pathogen *Erwinia chrysanthemi* was more severe in the sandiest soil (Bolanos and Belalcazar, 2000). Poor soil structure, for example through compaction or poor drainage, increases the likelihood of serious pathogens (Ghorbani et al., 2008). Davies et al. (1997) reported that in the case of wheat take-all (*Gaeumannomyces graminis*), a low level of disease was tolerated in heavy soil with minimal effect on yield, whereas the same level was more harmful under poor drainage conditions caused by soil compaction (Davies et al., 1997).

Water is essential for both plants and pests to thrive and thus soil moisture also plays a role in soil–pest relationships. An optimum balance between water and air is key to plant health, and the amount of water in a soil is inversely related to the amount of soil aeration, (Weiland, 2012). Ghorbani et al. (2008) show that increased moisture levels appear primarily to benefit the pathogen. Similarly, plants are most severely affected by many soil fungi (e.g. *Phytophthora*, *Rhizoctonia*, *Sclerotinia*), some bacteria (e.g. *Erwinia* and *Pseudomonas*) and most nematodes when the soil is at field capacity moisture but not flooded. Dry conditions can also weaken plants and may predispose them to pests and pathogens; for example, the invasion of groundnuts by *Aspergillus flavus* is more likely under conditions of drought stress (Wotton and Strange, 1987).

Soil temperature affects the rate of seed germination, plant growth, and the development and survival of soil pests, but has less influence on plant diseases than soil moisture levels. Ghorbani et al. (2008) cite Pathak and Srivastava (2001), who report that increased soil moisture and decreased soil temperature limited the development of *Rhizoctonia bataticola* in sunflowers.

Soil pH is important in soil fertility and nutrient availability. The availability of some micronutrients (e.g. iron and manganese) increases in slightly acid soils, whereas others (e.g. aluminum) may become toxic at lower pH levels. Soil pH influences plant disease infection and development directly through its effect on soil-borne pathogens and microorganisms and indirectly by its influence on nutrient availability (Ghorbani et al., 2008).

Some studies reported in Ghorbani et al. (2008) observed a higher infection of peanut stems by *Sclerotium rolfsii* at soil pH 5.6 than in more alkaline soil, although infection did still occur at soil pH of 8.7 and 9.8 (Shim and Starr 1997). Potato common scab (*Streptomyces scabies*) has been found to be severe from pH 5.2 to 8.0 or above (Dominguez et al., 1996), but is generally suppressed at lower pH levels (Sullivan, 2001). Studies on *Fusarium* wilts in banana plants have also observed relationships between disease incidence and pH values, as well as cation exchange capacity (CEC), sodium in solution, and iron (Dominguez et al 1996).

The role of several soil nutrients has been investigated, but nitrogen and potassium have been studied in more detail, finding that an excess of nitrogen exacerbates plant growth, making the plant more attractive, and increasing the incidence of pests and disease (Reddy, 2017). A good supply of phosphorus helps plants to resist diseases (Reddy, 2017), especially bacterial diseases, and provides tolerance to infections. Potassium also improves disease resistance (Reddy, 2017) by maintaining tightly closed stomata; it also improves stem strength, which reduces lodging, and in turn reduces insect and disease damage and maintains crop quality. Calcium is reported to suppress the incidence of club root in cruciferous plants. Boron deficiencies render plants more susceptible to powdery mildew (Roy et al., 2006).

Significant research on the role of organic matter (OM) in managing of soil-borne diseases has been conducted (Weiland, 2012). Organic matter as used in crop protection leads to increased microbial activity, reduced and weaker infestation by pathogens, increased viral resistance and reduced soil tiredness or toxicity (Ghorbani et al., 2008). Soils lacking vegetative cover are also exposed to greater temperature and moisture extremes that may contribute to pathogen mortality. Significant reductions in soil-borne pathogens such as *Pythium*, *Fusarium*, and *Cylindrocarpon* species have been observed and, in several cases, bare fallow has proved as effective as fumigation in reducing pathogen populations (Weiland, 2012). The positive effect of organic matter on nitrogen fertility is also significant given the influence of nutrient effects on the severity of pathogen infections noted earlier (Ghorbani et al., 2008).

Socio-economic characteristics of the farmer

In the review made by Delgado et al. (2021b), Kaminski and Christiaensen (2014), Maiziku (2020), Doki N.O., Eya C.I., Tuughgba M.F., Akahi O.G., Ameh A., (2019), and Gebretsadik, D., Haji, Jema., & Tegegne, B. (2019) find human capital, or education and experience, to be negatively correlated with loss reduction of, i.e. higher the education lower the level of FL.

Market access

As stated by Blakeney, 2019, the absence of an effective transportation infrastructure, particularly in developing countries, can be a major cause of FLW. Poor roads and a lack of suitable vehicles contribute to the deterioration of perishable commodities during transport.

Rosegrant et al. (2015) find that better infrastructure facilitating transportation of products to markets reduces post-harvest losses, but that the impact is stronger if farmers have better education and are thus able to adopt proper crop handling and processing techniques. They further find that post-harvest losses are correlated with farm size. Larger farms are more likely to incur post-harvest losses but experience fewer losses in the intensive margin. The overall impact suggests a negative relationship between the share of post-harvest losses and farm size.

Mechanization and technology

The review of the evidence by Delgado et al. (2021b) found that Kasso and Bekele (2016), Macheka, L. et al. (2018), Kumar, D. Kalita, P. (2017), Folayan (2013), Paneru, R. et al. (2018), and Maziku (2020) identify lack of storage and transportation facilities as important factors behind the losses of horticultural and maize crops, respectively.

The risk of food loss is further escalated by poor post-harvest crop management techniques and handling. Which techniques constitute proper handling may vary. Tefera (2012) finds that improper post-harvest crop management and harvesting techniques in Africa account for between 14% and 36% of losses in maize grains. Insufficient or excessive drying and missing grains are some of the problems at the harvesting and drying stages. Others include improper threshing and shelling, which can cause grain breakage and grain cracking, predominant in this stage; transportation to store; and on-farm storage. Transportation to market and marketing are also critical areas where maize losses occur. Studies also point to credit constraints as a bottleneck to technology adoption, preventing food loss reduction. (HLPE, 2014)

Storage facilities and growing conditions (pests and disease)

Savary et al. (2012) note that the crop losses caused by plant disease affect food availability and other factors, such as the food utilization component, directly or indirectly through the fabrics of trade, policies and societies (Zadoks, 2008). Savary et al. (2012) report that the combined yield losses caused by pathogens, animals and weeds account for reductions ranging between 20% and 40 % of global agricultural productivity (Teng and Krupa 1980; Teng 1987; Oerke et al., 1994; Oerke, 2006). Post-harvest quality losses and the possible accumulation of toxins during and after the cropping season must be considered.

Insects and pest attacks on produce have also been identified as important causes, typically compounded by heat or moist and poor storage conditions. Chegere, M. (2018) and John (2014), for instance, find that rodents are a major factor for post-harvest loss (PHL) of rice in Southeast Asia. Abdoulaye et al. (2016) report that more than 75% of farmers in Ghana, Tanzania, and Benin identified insects as the major cause for PHL, while most farmers in Ethiopia, Uganda, and

Nigeria complained about rodents and moisture as main causes for PHL. Finally, Compton et al. (1997) and Baoua et al. (2014) show that each percentage point of insect infestation results in between 0.6% and 1% depreciation in the value of maize. Certain climatic conditions, especially heat and moisture, tend to increase the prevalence of insects, pests and other bio-deterioration factors, especially when proper storage and transportation structures that control temperature and humidity are lacking.

Aflatoxin is a potent carcinogen produced by *Aspergillus flavus*, which frequently contaminates maize (*Zea mays* L.[9]) in the field. Several studies have developed models to predict aflatoxin contamination but not their effect on losses or PHL. A mechanistic model to predict risk of pre-harvest contamination could assist in management of this harmful mycotoxin by identifying locations at a specific time where aflatoxin has a higher probability of being present.

Predictions related to actual data describe the risk of aflatoxin contamination during the current growing season, day by day, from its emergence until the harvest. High aflatoxin contamination is commonly associated with high stress for plants and fungi mainly caused by high temperature and drought (Moreno and Kang, 1999). In the other hand, frequent rains in autumn can delay cereal harvests, reducing grain quality due to sprouting and increased mycotoxin contamination. Grain quality was thus reduced from food to fodder grade with consequential price reductions (Savary et al., 2012). Even if predictions cannot support operational decisions, such information is useful as harvest approaches. Aflatoxins accumulate over time during maize ripening and late harvest is associated with increased contamination (Cotty and Jaime-Garcia, 2007). When the contamination risk is high for *Aspergillus flavus* aflatoxin and there is high humidity in the kernels, an early harvest is strongly suggested.

Climatic Conditions

Blakeney et.al 2019 found that climatic and environmental factors have an obvious effect upon yield, with climate change inflicting a series of agricultural

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9 https://plants.usda.gov/java/ClassificationServlet?source=profile&symbol=ZEMA&display=31

stresses through increases in heat, salinity and pest infestation. High temperatures have been reported to cause physiological disorders in crops. Temperature extremes can predispose to aflatoxin contamination rendering food unsafe and requiring it to be discarded.

Although, there was no evidence about the direct relation of lack of, or excessive, rain and post-harvest losses, some studies support the idea that certain weather conditions could be directly related to the presence of pathogens such as aflatoxins. The association with climate is because *Aspergillus flavus* is commonly found in soils in tropical and sub-tropical climates between latitudes 35 degrees north and south of the equator (Klich, 2007; and Abbas et al., 2009). Many factors can influence the crop colonization, growth, and toxin production of *Aspergillus* species, including heat, humidity, pest or environmental host stressors, and post-harvest practices (Abbas et al., 2009).

2.5 What we know on interventions

Stathers et al. (2020) systematically review PHL reduction interventions for 22 crops across 57 countries in sub-Saharan Africa and South Asia from the 1970s to 2019. The authors review 12,786 papers and select 334 from which to create a synthesis evidence on the effectiveness of different interventions. Storage technology interventions targeting farmers dominated (79% of studies). Maize was the most studied crop (23%). Most interventions studied were in India (33%), while 24 countries had no studies. The lack of studies related to training, finance, infrastructure, policy and market interventions in the assessment highlight the need for study of interventions that go beyond technology or handling practice changes.

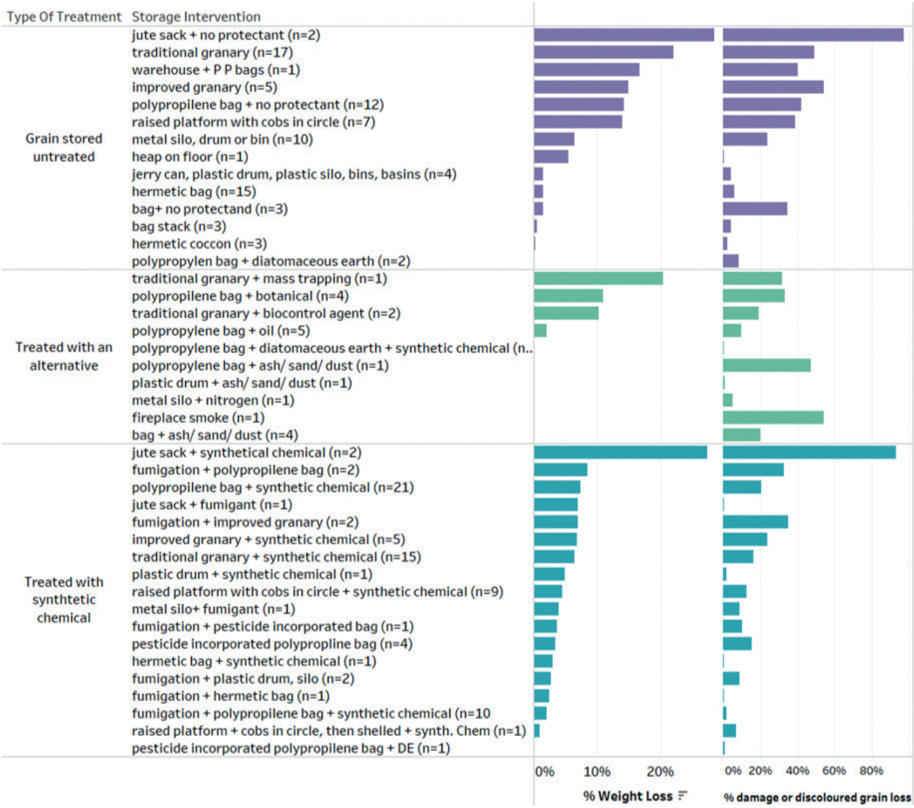

Figure 2.6: Comparative loss in quantity of maize stored using different storage interventions. Source: Author's elaboration based on Stathers et al. (2020)

Note: The mean % weight loss and 95% CIs for each of the storage interventions tested on maize stored for a duration of 6 months are listed, with the most effective interventions at the top and the least effective at the bottom of the list. The n number indicates the number of times this intervention was found in the 334 studies. Interventions in which the grain was stored untreated are shown as purple bars. The blue bars indicate grain treated with a synthetic chemical. The green bars indicate grain treated with an alternative method.

Figure 2.6 presents the results of the impact of different types of interventions of grain storage in terms of percentage of weight loss and percentage of discolored grain loss. It demonstrates the variance across the different types of interventions, with hermetic bags proving the most effective, as well as the use of synthetic chemicals. A major limitation of almost all these studies is that cost effectiveness assessment was not assessed. Table 2.1 summarizes the different types of storage interventions that had been implemented and describes the interventions that had have a significant impact.

Table 2.1: Interventions to reduce food losses

Technologies	Examples	Description	More information	Studies
Plastic silos		Plastic PVC storage units –similar to locally produced water containers– that provide effective rodent and pest protection.	**Advantages:** a) Durable, b) Strong performance, c) Large capacity and d) Less expensive than metal silos. (Viola et al. 2017) **Disadvantages:** a) Challenged with maintaining hermiticity around seals and b) difficult to deoxygenate when filling. (Viola et al. 2017)	Abass et al. (2018); Walker et al. (2018)
Hermetic Storage	Metallic silos	Strong hermetically sealed structure, built using galvanized teel sheet. (Kumar et al. 2017)	Very effective for storing grains for long periods of time and avoiding insects and rodents (Kumar et al. 2017)	Abass et al. (2018); Walker et al. (2018); De Groote et al. (2013); Gitonga, et al. (2013); Tefera et al. (2011)
	Purdue Improved Cowpea storage (PICS) bags	Involve triple bagging the grains in hermetic conditions. The grains are stored in double layer thick (80 µm) high density polyethylene (HDPE) bags and is held in a third woven nylon bag. (Kumar D. et al. 2017)		Abass et al. (2018); Walker et al. (2018); Baoua et al. (2012); De Groote et al. (2013); Murdock et al. (2014); Baoua et al. (2013); Mutungui et al. (2014); Sudini et al. (2015); Baoua et al. (2014)
	Super grain bags	Multi-layer polyethylene bags, usually placed inside ordinary storage bags for additional protection. Water resistant and hermetic. (Viola et al. 2017)	**Advantages:** a) Easy to handle and transport, b)perform very well and c) do not require pesticides and are the most affordable solution. (Viola et al. 2017) **Disadvantages:** a)Limited capacity, b) Shorter life span and c) Do not provide rodent protection. (Viola et al. 2017)	Likhayo et al. (2018); Walker et al. (2018); De Groote et al. (2013)
GrainPro Bags		Made of food-grade, UV-resistant flexible PVC, it is designed for both indoor and outdoor installations. Is a water-resistant and hermetic (https://www.adaptive.ag/shop/grainsafe)	It can store commodities at or below safe moisture content for prolonged periods without the risks of moisture ingress, pest infestation and fungal growth. (https://www.adaptive.ag/shop/grainsafe)	Walker et al. (2018); Baoua et al. (2013)
ZeroFly bags		The bag is made with pyrethroid incorporated into polypropylene yarns. No hermetic. (Kumar D. et al. 2017)		Abass et al. (2018); Paudyal et al. (2017); Paudyal et al. (2017)
Cold chain		Uninterrupted handling of the product within a low temperature environment during the postharvest steps of the value chain until it reaches the final consumer.(Kitinoja, 2013)		Kitinoja et al. (2010); Kitinoja (2013)

Technologies	Examples	Description	More information	Studies
Dry Storage	Solar dries	Solar radiation passes through a transparent aperture and retained as heat in a drying chamber, a solar collector, or both. (Tomar, et al. 2017)		Esper et al. (1998); Chua et al. (2003); Tomar et al. (2017); Salvatierra-Rojas et al. (2017)
	Convective dryers	Generally used for drying piece-form fruits and vegetables, potential in small farming areas where electricity is available (Chua et al. 2003)		Chua et al. (2003)
	Drying beads	Modified ceramic materials (aluminum silicates or "zeolites") that specifically absorb and hold water molecules very tightly in their microscopic pores. (http://www.dryingbeads.org/)		Bradford et al. (2018)
Gum Arabic Coating		An edible extract from certain species of acacia trees, can be applied in an aqueous solution to fruits and vegetables to increase their shelf life		Asgar et al. (2013); Ghulam et al. (2015); Binsi et al. (2016)
Returnable plastic crates (RPC)		RPCs are the many shapes and sizes of plastic crates. They are mostly use as containers for packing fresh produce with the purposes of easy handling and to protect the produce during handling. (Kitinoja, 2013)		Kitinoja (2013)
Fumigation	Chemical Fumigation	Synthetic insecticides are used in several countries and play an important role in controlling the pests and reducing losses during storage of grains (Kumar et al. 2017)		De Groote et al. (2013); Abass et al. (2018)
	Natural fumigation	Several plant species and their extracts have been found with natural pesticide ability and are used very commonly as a traditional practice to protect the grains from insects in several African and Asian countries (Kumar et al. 2017)		Shaaya et al. (1997); Kumar et al. (2006)

Source: Own elaboration by authors

2.6 Conclusions

The SDGs emphasize both increasing food security and reducing stress on natural resources. Reducing food loss and waste can make a critical contribution to these broad goals. SDG 12 focuses specifically on sustainable consumption and production patterns. SDG target 12.3 calls for halving global food waste at the retail and consumer levels, and reducing food losses along the value chain by 2030. In addition to these targets, the Committee on World Food Security has called on all public, private, and civil society actors to promote a common understanding of food loss and waste and to create an enabling environment for its "food use-not-waste" agenda, especially for monitoring, measurement, and reporting targets.[10] And in May 2015, the G20 agriculture ministers highlighted the global challenge of preventing and reducing food loss and waste, and encouraged all G20 members to strengthen their collective efforts.

In this context of international commitment, identifying the magnitudes, causes, and costs of food loss and waste across the value chain is critical for setting priorities for action. Identifying appropriate places for intervention will require an integrated value chain approach and the coordination of a wide diversity of actors, including multidisciplinary researchers, policy-makers, and private sector and civil society actors. Addressing loss and waste will require a common understanding of the concept[11] as well as a collaborative effort to collect better micro-data across different commodities and contexts. To achieve target 12.3, we need to set concrete targets at both regional and country levels, and specifically address the relevant differences between developing and developed countries. For developed countries, the focus should be on waste; for developing countries, the focus in the short term should be on food loss, but it should also give attention to how to leapfrog to best practices for reducing waste.

To be able to set and monitor verifiable targets, it is essential to improve the methodology used to measure food loss across food value chains, and identify

[10] Committee on World Food Security (CFS), Report of the 41st Session of the Committee on World Food Security (Rome: October 13–18, 2014).

[11] A good step in this direction has been made by the multistakeholder Food Loss and Waste Protocol initiative, although this initiative excludes preharvest losses from its definition.

the causes and costs of loss across value chains. It is critical to promote food loss reduction interventions and set priorities for action. We address the existing measurement gap by implementing a literature review of the different ways in which losses has been measured. We also bring a new definition, Potential Food Loss and Waste, which includes the opportunity cost of the land being used by farmers.

Addressing food loss across the value chain first requires a common understanding of the concept by all actors,[12] as well as a collaborative effort to collect better micro-data across different commodities and contexts. The presence of pests, lack of rainfall, and lack of appropriate post-harvest technologies seem to be the major factors behind the losses identified in our study. A lack of appropriate storage facilities (FAO, 2011; Liu, 2014) and efficient transport systems (Rolle, 2006) are also considered to be important micro-causes of food loss. However, other causes, ranging from crop variety choices, pre-harvest pests, and processing and retail decisions, are also notable. Micro-causes can be linked to broader meso-causes, overarching different stages of the value chain; for example, the HLPE report (2013) sees credit constraints as one of the main bottlenecks to the successful adoption of technologies to reduce food loss and waste. As Kaminski and Christiansen (2014) argue, lack of education is an important bottleneck.

Governments should focus on ensuring that public-sector investments facilitate reductions in food loss and waste. Such investments include a broad gamut of areas related to food systems and can have multiple benefits: information on best practices, food safety, education, roads, regulations and standards, and addressing market failures. Smallholders, in particular, who produce only small surpluses, often face substantial market failures that contribute to food loss and waste. Public-sector investment can address some of these shortcomings, such as the need for appropriate storage facilities, efficient transport systems, policies that improve access to credit, support for market incentives for improved food safety (as in the case of aflatoxins), and access to crop varieties resistant to

[12] A good step in this direction has been made by the multi-stakeholder "Food Loss and Waste Standard and Protocol" initiative, although this initiative does exclude pre-harvest loss from its definition.

weather shocks.[25] For example, food quality and safety standards not only facilitate export of produce grown in Africa to international destinations, but also help ensure that smallholder farmers and their families fully benefit from high-quality, nutritious food grown locally. The private sector also has a role to play, particularly when reducing food loss and waste can generate profits. For example, choosing appropriate crop varieties, dealing with pre-harvest pests, and making processing and retail decisions may be best addressed by the private sector.

Analyzing the factors affecting food loss and waste at the micro-, meso-, and macro-levels can help in identifying effective reduction interventions.[13] Looking at the micro-level causes of food loss and waste, studies point to credit constraints as one of the main bottlenecks to technology adoption to reduce food loss and waste.[14] Others point to the importance of education,[15] contractual practices,[16] and the growing need to improve infrastructure, particularly in rural areas.[17]

Micro-level causes can be linked to broader meso- and macro-level causes that overarch different stages of the value chain. For example, strict food safety concerns and regulations can lead to safe food being rejected for import or removed from markets.[18] Other systemic causes relate to inappropriate technologies, changing consumer demands, and low capacities to adopt innovations or respond to changing consumption patterns. Thus, context-specific

13 HLPE, Food Losses and Waste in the Context of Sustainable Food Systems—A Report by the High-Level Panel of Experts on Food Security and Nutrition

14 HLPE, (2014).

15 J. Kaminski and L. Christiaensen, (2014).

16 J. Parfitt et al., (2010).

17 M. W. Rosegrant, et.al. 2015. find that electricity, roads and railways play an important role in PHL reduction. After obtaining estimates of infrastructure on PHL reductions they use the cost of infrastructure development to estimate a number of investment scenarios. These scenarios were later implemented in the IMPACT global food supply and demand model (IFPRI) to simulate the impact of PHL reduction on food prices, security, consumer and producer surplus, net welfare gains and benefit cost ratios to the investment. Overall, reduction in PHL was not found to bea low-cost alternative; rather it requires large investment and is complementary to long term investments to achieve food security.

18 J. Fonseca and D. Njie, (2013).

cost-benefit analyses have to be systematically carried out to identify the most sustainable and efficient interventions for reducing loss and waste.

Finally, policy-makers and value chain actors need to translate knowledge into action. International organizations have the power to bring this important topic to the table and create platforms for information exchange — such as the technical platform on measurement and reduction of food loss and waste launched by the International Food Policy Research Institute and FAO as a result of the G20 summit in Turkey in December 2015. [19] States also have a key role to play in creating an enabling environment, and all public and private value chain actors need to transform insights about food loss and waste into concrete interventions in order to generate the multiple benefits of increased food availability and reduced environmental pressures.

[19] See FAO Technical Platform on the Measurement and Reduction of Food Loss and Waste, http://www.fao.org/ platform-food-loss-waste/background/en/.

Chapter 3

Quantity and Quality Food Losses Across the Value Chain: A Comparative Analysis

The essential first steps of addressing the problem of food loss are measuring the loss, identifying where in the food system it occurs, and developing effective policies to mitigate it along the value chain. Food loss has been defined in many ways, and disagreement remains over proper terminology and methodology to measure it. In addition, none of the current classifications includes pre-harvest losses, such as crops lost to pests and diseases before harvest. Consequently, figures on food loss are highly inconsistent. The precise causes of food loss remain undetected, and success stories of reducing food loss are rare. We address this measurement gap by developing and testing three new measurement methodologies, as well as one traditional methodology. Our proposed methods account for losses from pre-harvest to product distribution and include both quantity losses and quality deterioration. We apply the instrument to producers, middlemen, and processors in five staple food value chains in six developing countries. Comparative results suggest that losses are highest at the producer level and most product deterioration occurs before harvest. Aggregated self-reported measures, which have been frequently used in the literature, consistently underestimate actual food losses.

This chapter is based on:

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3.1 Introduction

Food loss and food waste have become an important topic in the development community. In fact, the United Nations included the issue of food loss and waste in the Sustainable Development Goal target 12.3, which aims to "halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" by 2030. Policies have aimed mainly at increasing agricultural yields and productivity, but these efforts are often cost- and time-intensive. In addition, food loss entails unnecessary greenhouse gas emissions and excessive use of scarce resources. Finally, the loss of marketable food can reduce producers' income and increase consumers' expenses, likely having larger impacts on disadvantaged segments of the population. There are few success stories of reducing food loss (World Bank, 2011) and food waste (WRAP, 2009; WWF-WRAP, 2020). Figures on food loss and food waste also remain highly inconsistent. Consequently, even though various governmental and civil society initiatives have been launched to address this important issue, significant results are yet to be seen.

There are three important challenges to implementing a strategy to reduce and prevent food loss and waste. First, there is no accurate information on the extent of the problem, especially in low- and middle-income countries. For the most part, calculations of food loss hinge upon accounting exercises that use aggregate data from food balance sheets provided by national or local authorities (figure 3.3). This macro-approach estimates, however, are often subject to large measurement error, frequently rely on poor quality data, particularly in low- and middle-income countries, and are not based on representative samples for specific stages of the value chain. More recently applied micro approaches use sample survey data regarding specific value chain actors to overcome shortcomings of the macro approach. However, these micro approaches are costly and time-consuming to implement. In addition, it can be difficult to get a large enough proportion of responses to represent an entire value chain or region across several years. Results are also hard to compare. Second, there is only scarce evidence regarding the source or cause of food loss. Because of the aggregate nature of their data, macro studies are unable to capture the critical stages at which food loss occurs. Most micro studies capture total food loss based on producers' self-reported estimates, but do not capture detailed information regarding the relative amounts of food loss incurred by different sources. Third, there is little evidence regarding how to reduce the losses effectively, and lack of knowledge around designing policy to incentivize food value chain actors to reduce losses. There have been efforts to introduce particular technologies along specific stages of the value chain (e.g., silos for grain storage, triple bagging for cowpea storage, or mechanized harvesting and cleaning equipment for wheat and maize).[20] However, little is known about adoption rates of these efforts, the economic sustainability and effective policy designs, especially in low-income contexts.

This paper aims to resolve the first two challenges. Our objective is to improve how food loss is quantified, to characterize the nature of food loss across the value chain for different commodities in a wide array, and to disentangle the different production and post-production processes in which losses occur. We build on the definition by FAO (2014), HLPE (2014) and Lipinski et al. (2013), and expand it by including pre-harvest losses. We include both quantitative losses and quality deterioration in the definition of food loss. This is because from an integrated value chain perspective, pre-harvest conditions and qualitative losses have direct impacts on eventual (quantitative and qualitative) losses at later stages of the value chain due to differences in food product quality, storage and shelf-life, and transport suitability (Hoffmann et al., 2020). We do not look at intentional food waste at the end of the value chain owing to the challenges in capturing such data, which would require developing a widely "accepted sampling and measurement framework." Such framework would likely comprise a mixture

[20] Chatterjee (2018) looks into the impact of storage infrastructure on agricultural yield by using the subsidy program given for construction and renovation of rural godowns in India. The author finds that this subsidy program for better storage infrastructure led to an increase in the rice yield by 0.3 tons per hectare — a 20 percent increase from the baseline. According to the author, the reduced storage costs have led to an investment in productive inputs.

of methods, such as waste composition analysis, questionnaires, interviews, or waste diaries (WRAP, 2013).[21]

We quantify food loss through three new measurement methodologies and one traditional methodology. We follow a framework similar to that of De Mel et al. (2009) by exploring different ways to measure food loss to identify how far we can reconcile loss figures across estimation methods. For this, we designed a sampling method that allows us to have representative samples at different nodes of the pre-consumption value chain and developed a set of surveys to measure the extent of food loss using the four methods in each of the specific nodes (i.e., producers, middlemen, and processors). While the surveys were tailored to specific countries, commodities, and commodity varieties, they provide a consistent measurement of food loss across different agents in the value chain.

We implemented specially designed surveys to capture food losses along five staple food value chains in six countries (potato in Peru and Ecuador, maize and beans in Honduras and Guatemala, teff in Ethiopia, and wheat in China). Applying this methodology to five different commodities in countries in different regions allows us to increase the potential external validity of the surveys. The results reveal the extent of the loss and the specific areas that require investments to reduce food loss.

3.2 Divergence in terminology and definitions

The literature commonly agrees on the need to measure food loss along different value chain stages (Figure 3.1) and the fact that food loss may occur at each stage (e.g., FAO, 2011; Lipinski et al., 2013; Parfitt et al., 2010). However, there is no agreement regarding further classification of food loss and food waste. The terms “Post-Harvest Losses” (PHL), “Food Loss” (FL), “Food Waste” (FW), and “Food Loss and Waste” (FLW) are frequently used interchangeably, but they hardly ever refer consistently to the same concept. For some authors, the distinction is linked to the stages at which

[21] Note that our definition differs from the one used by Bellemare et al. (2017), which includes food waste, but does not include qualitative product deterioration.

the loss occurs. For others, the distinction is based on the cause of the food loss and whether it was intentional.

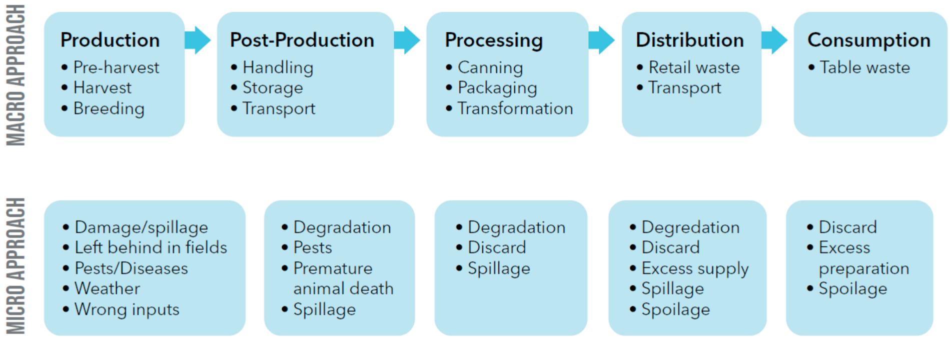


Figure 3.1: Food Losses along the Value Chain**.** Source: Authors' elaboration

Recent publications have tried to provide more clarity (FAO, 2014; HLPE, 2014; Lipinski et al., 2013). In these studies, FL refers to unintentional reductions in food quantity or quality before consumption. These losses usually occur in the earlier stages of the food value chain, from production to distribution, but they also occur during wholesale and retail. PHL is an element of FL and excludes losses at the production level, although losses during harvest are sometimes misleadingly included in the concept (e.g., Affognon, 2014; Hodges et al., 2014). FW refers to food that is fit for human consumption but is deliberately discarded; this is most common toward the end of the value chain at the retail and household level.[22] The totality of losses and waste along the value chain with respect to the total harvested production is encompassed in the FLW concept (FAO, 2014). However, this definition does not include crops lost before harvest because of pests and diseases, crops left in the field, crops lost due to poor harvesting techniques

[22] Bellemare et al. (2017) uses food life cycle approach, which includes grower, processor, retailer, and consumer, to give a new and contrasting definition of food waste. According to this definition, food waste is the "difference between the amount of food produced and the sum of all food employed in any kind of productive use, whether it is food or non-food." On the basis of a simple theoretical relationship and numerical examples, the authors explain that both quantity and the value of food waste is overstated by other definitions, citing Buzby et al., FAO, and FUSIONS.

or sharp price drops, or food that was not produced because of a lack of adequate agricultural inputs, including labor availability.

There is also no agreement in the literature regarding the definition of food loss at each stage of the value chain. For example, losses across the value chain can originate from reductions in both food quantity and food quality and can thus describe either weight, caloric, nutritional, and/or economic losses. Due to estimation difficulties, product seasonality, and market sensitivity to food quality, most studies analyze the quantity of food loss in terms of weight reductions (e.g., Hodges et al., 2014; HLPE, 2014). Some studies further translate quantity losses into caloric terms (e.g., Buzby et al., 2014; Kummu et al., 2012; Lipinski et al., 2013), but do not capture qualitative dimensions such as loss of nutritional content and physical appearance (Affognon et al., 2014). The choice of definition has important implications for the estimation methodology used to examine food loss and for the interpretation of results.

3.3 How food losses have been measured

Two main estimation methodologies have been used to study food loss across the value chain: a macro approach, using aggregated data from national or local authorities and large companies, and a micro approach, using data regarding specific actors in the different value chain stages (Figure 3.2).

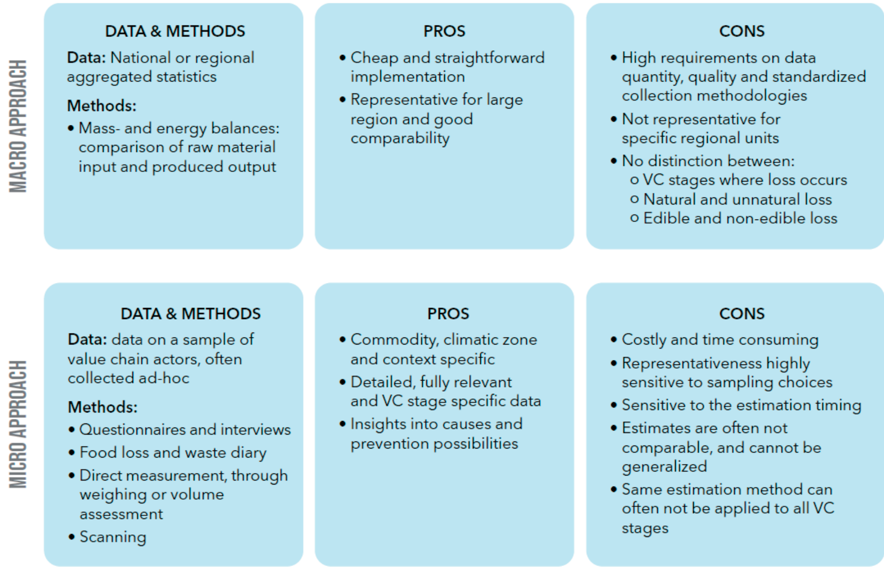


Figure 3.2. Food Losses Estimation Methodologies. Source: Authors' elaboration

The macro approach relies on mass or energy balances, in which raw material inputs, in either weight or caloric terms, are compared to agricultural production and food products. This method is a low-cost way to obtain an indication of the overall losses along the entire value chain and was used by Gustavsson et al. (2011). The study is widely used as a reference for estimates of food loss and waste at the global level. By using the Food Balance Sheets from FAOSTAT (2019), the study estimates that around 32 percent of global food production, across all production sectors, is lost along the entire food value chain.[23] Kummu et al. (2012) and Lipinski et al. (2013) use the same raw data and find that this translates into a 24 percent

[23] The macro approach of Gustavsson et al. (2011) looked at the mass of the food produced and its utilizations, estimating losses with a mix of balancing equations and loss factors from the literature. Their method covered all steps from agricultural production to consumption through a series of assumptions. Produced outputs refers to the total production for all commodities analyzed. The study only considered edible parts of the food, and treated all non-food uses (feed, seed, and industrial use) as loss or waste. In addition, the study considered food loss and waste only in terms of quantities without taking into account the different values of different commodities.

decrease in caloric terms. In country-specific studies, macro energy balances show that 48 percent of the total calories produced are lost across the whole food value chain in Switzerland (Beretta et al., 2013). Mass balance data series from the U.S. Department of Agriculture, using alternative assumptions, show that 28.7 percent of the harvested product is lost between post-production and consumption in the United States (Venkat, 2011), and that 31 percent of the available U.S. food supply is lost during distribution and consumption (Buzby et al., 2014).

One disadvantage of the macro methods is the lack of representative and high-quality data on production, loss, and waste. Data gaps are particularly apparent for certain regions of the world, such as low- and middle-income countries, and specific stages of the value chain, such as primary production, processing, and retail (Stuart, 2009). The method is also not representative of smaller regional units, preventing identification of the value chain stages at which the losses occur and challenging the appropriate targeting of loss reduction interventions. Finally, the aggregate data used for mass balances are often incapable of differentiating between natural loss (e.g., moisture loss) and unnatural weight loss (e.g., caused by spoilage), as well as edible and inedible losses.

The micro approach, on the other hand, uses sample survey data regarding specific value chain actors. Different methods are used to obtain data: structured questionnaires and interviews, food loss and waste diaries compiled directly by the value chain actor, direct measurements by the researcher, and food-scanning methods, which can be used in developed retail markets. These methods are highly region- and context-specific, are useful in disentangling the origin of loss along the value chain, and tend to provide more insights into causes and possibilities of prevention. The study by the African Postharvest Losses Information System (APHLIS) estimates that primary production and post-harvest weight loss for cereal crops in sub-Saharan Africa to be between 14.3 and 15.8 percent of total production (Hodges et al., 2014). Kader (2009) reviews previous estimates of losses in both developing and developed countries and finds an average of 32 percent loss for fruits and vegetables. Official Eurostat data are used in the study by

Monier et al. (2010) to quantify losses along different stages of the food value chain for 27 EU member states. By excluding waste at the agricultural production level, Eurostat estimates an annual average of 89 million tons of waste (i.e., 179 kg per capita). A study by WRAP (2010) analyzes waste from the U.K. food and drink supply chain and finds that across processing, distribution, and consumption, 18.4 million tons of total food and drink are wasted annually in the U.K.; households are responsible for the largest share, wasting 22 percent of their purchases (WRAP, 2009).

The main challenges for the use of these micro methods to estimate food loss is the cost and time to implement the studies, as well as the difficulty in getting a large enough proportion of responses to represent an entire value chain or region. In addition, results are hard to compare because studies are adapted to their specific objective, focus only on specific stages of the value chain, and use different data collection and estimation methodologies.

Figure 3.2 summarizes the two approaches to FLW estimation, highlighting their advantages and drawbacks. Figure 3.3 provides a global overview of the magnitude of FLW from recent studies, distinguishing the two estimation approaches.[24] A review of 213 papers on food loss and waste in sub-Saharan Africa identified large differences in estimates attributable not only to the choice of methodology, but also to factors such as agro-ecological conditions, technology, and socioeconomic contexts, affecting both production and post-production (Figure 3.3). In addition, Sheahan and Barrett (2017) review various dimensions of the literature on food loss and waste in sub-Saharan Africa. The authors point out that there is a large gap and no clear consensus on the estimates. The authors recommend the application of a new survey method employed in Asia by Minten et al. (2016a) be adopted more widely. The paper also highlights that there is no importance given to food quality losses, and that there is a paucity of research examining the ideal percentage of losses.

[24] This does not intend to be a complete literature review. It merely provides reference on estimates from previous research. We selected studies encompassing more than one level and/or commodity of the value chain. For a complete literature review, please see Affognon (2015), Møller et al. (2013), or Kader (2009).

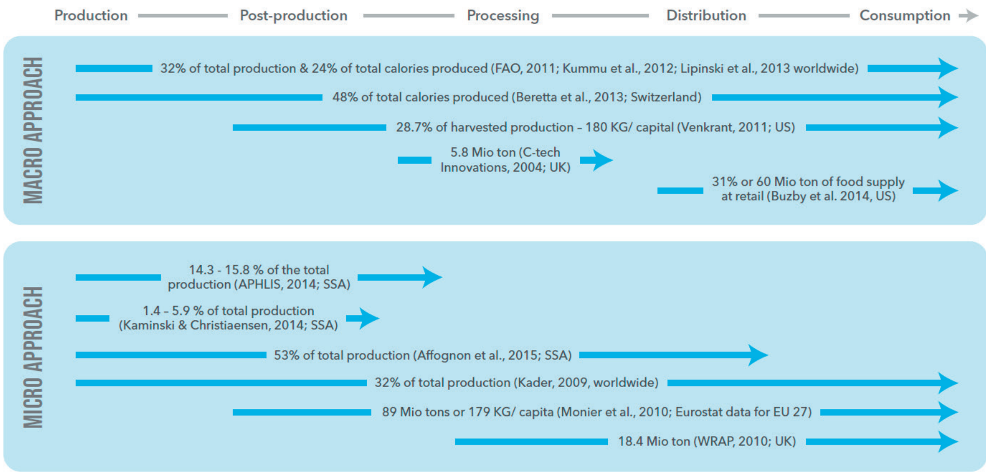


Figure 3.3. Estimation of Food Losses. Source: Authors' elaboration

A standard definition and terminology for food loss and waste is crucial. But this by itself will not be enough to identify the underlying causes and potential solutions to food loss and waste or to monitor specific progress on reduction targets. To be most useful, the definition should adopt a value chain approach and include pre-harvest losses. While there is no well-documented evidence in the literature about direct relationship between pre-harvest agronomic factors and food loss and waste, there is evidence that some pests, weeds, pathogens, and weather conditions are associated with the presence of some pathogens, such as aflatoxins and fungus, which could affect the produce both in quantity and quality, and therefore its market value (e.g., Abbas et al., 2009; Hoffmann et al., 2020).[25] Rooted in this definition, goals for reducing food loss and waste must include both quantitative and qualitative criteria, measurable in economic, caloric, or quality-adjusted weight terms. In addition, assessments must identify loss and waste occurring at particular value chain stages. FLW measurement

[25] For example, according to Savary et al. (2012), direct pre-harvest losses caused by pathogens, animals, and weeds are altogether responsible for losses ranging between 20 and 40 percent of global agriculture.

must also take into account that food loss and waste often originate at different stages along the value chain in different geographical locations.[26]

Estimation methods used for low- and middle-income countries should differ from those used in high-income countries because of data availability. The methodology for developing countries should measure food reductions at different stages of the value chain and should be applicable across crops and regions. Representative surveys of farmers, middlemen, wholesale buyers, and processors should allow for the characterization of inputs, harvesting, storage, handling, and processing practices for each of these agents. They should also consider the estimation of product quantities, quality, and prices along the value chain.

In developed countries, detailed data on food loss and waste in the processing, distribution, wholesale, and retail stages are often tracked by companies, but are not made available to researchers and policymakers. Transparency should be encouraged in order to systematize data collection and to increase access to reliable food loss and waste information. The methodology must capture both quantitative and qualitative food loss, as well as discretionary food waste in the processing, large distribution, and retail sectors. Food service waste and household waste are more challenging to capture. It would require collecting representative samples using a variety of methods, such as waste composition analysis, questionnaires, interviews, or waste diaries (WRAP, 2013).

3.4 Proposed empirical approach

By drawing on the literature and economic theory, we propose three alternative methodologies, in addition to the traditionally used methodology of *aggregate self-reported measures* of loss. All four methodologies can measure losses at different stages of the value chain and can be applied across crops and regions. The methodologies are based on

[26] In developing countries, food loss tends to occur in the early stages of the value chain and represents a common bottleneck; in industrialized regions, food waste is widespread and results from food system decisions and consumer negligence at later stages of the value chain (FAO, 2011; Hodges, 2010; Kader, 2005; and Parfitt et al., 2010).

information collected through representative surveys of producers, middlemen, and processors between the production and processing stages. These surveys must allow for the characterization of inputs, harvesting, storage, handling, and processing practices for each of these agents and estimate the quantities, quality, and prices of the production as it travels along the value chain.

All methodologies estimate both the total food that is lost (quantity degradation, estimated in quantity or value) and the product that, albeit not being completely lost, is affected by quality deterioration (estimated in quantity or value). At the producer level, we estimate losses from harvest to post-harvest sale, while the reference period is the last cropping season. For the middlemen and the processors, we estimate losses from purchase to sale, during a defined time period (depending on the country). Due to the heterogeneity of the crop transformation processes at later stages in the value chain, at the processor level, only the aggregate self-reported measurement method may be used. The four methodologies are outlined below.

Aggregate self-reported method

The "aggregate self-reported method" (S-method) is based on reporting by the producers, middlemen, and processors regarding the food losses they each incurred. Self-reporting of loss figures has been widely used in recent studies on food loss (e.g., Ambler et al., 2018, Kaminski and Christiansen, 2014; Minten et al., 2016a; Minten et al., 2016b).

Direct survey questions ask value chain actors about their quantity and quality degradation. At the producer level, the survey instrument includes questions about pre-harvest and post-harvest losses.[27] Middlemen and processors are asked about losses at different stages of post-harvest

[27] For example, at the producer level the following questions were asked to identify losses: In the last planting season, what is the quantity of your harvest (and value of that quantity) that was damaged previous to harvest?; What is the quantity (and value) that was left in the field?; What is the quantity (and value) that was lost during post-harvest activities?; What is the quantity damaged (and value of that quantity) during post-harvest activities?

activities and transformation processes. The appendix (Table 3.A1) provides insights about the exact survey questions used in the three (producer, middleman, and processor) survey instruments. The responses to the questions are added up to obtain the total loss figures in weight and values at the level of the three value chain actors.

Category method

The "category method" (C-method) is based on the evaluation of a crop and the classification of that crop into quality categories. The method builds on the "Visual Scale Method," developed by Compton and Sherington (1999), to rapidly estimate quantity and quality grain loss. The C-method classifies each product into its end use (i.e., suitable for export, the formal market, the informal market, animal feed, etc.). Each category is associated with a crop damage coefficient, a percentage between 0 and 100 representing the share of the product that is damaged from each category. The categories are established prior to data collection in collaboration with commodity specialists, local experts, and value chain actors and vary between four and six, according to the commodity and country. In addition, an extensive pilot was conducted to validate the categories. By means of the described categories and damage coefficients, producers are asked to evaluate their production at harvest and after post-harvest activities, while middlemen are asked to evaluate their product at purchases and sales. Both producers and middlemen indicate at which price they sell the produce in the different categories, as well as a sale price for ideal produce in the harvest and lean season.[28]

[28] The "ideal price" was calculated from the producer and middlemen surveys. It corresponds to the sample average of the stated best price (at the producer or middlemen level) for an ideal quality product during the harvest and lean season in the geographical area/commodity for which the survey was representative. This allows us to calculate the distance between the "actual price" a producer/middleman received and the "average ideal price" a set of comparable producer/middlemen received in the same geographical area. While we acknowledge the difficulty in establishing the reference point in practice, we believe that this is a reasonable approximation of the average "best value" that a producer/middleman could have received for its product. Finally, ideal prices do reflect the market conditions and

At the producer level, $WeightLoss_p$ is the physical quantity that disappears for producer *p* between harvest and post-harvest (quantity degradation) plus the post-harvest loss in each category based on an industry-defined rating of crop damage by category (quality degradation). $ValueLoss_p$ is the value of the physical quantity that disappears between harvest and post-harvest (quantity degradation) plus an industry-defined price punishment by category (quality degradation). $WeightLoss_p$ and Value$Loss_p$ are given by eq. 1 and 2, respectively:

$$WeightLoss_p = \left(Q_{Prod,p} - Q_{PH,p} \right) + \sum_{i=1}^{I} (C_i * QC_{iPH,p}) \quad (1)$$

$$ValueLoss_p = \left(V_{Prod,p} - V_{PH,p} \right) + \sum_{i=1}^{I} (\bar{P}_{ideal,p} - \bar{P}_{Ci,p}) * QC_{iPH,p} \quad (2)$$

where $Q_{Prod,p}$ and $Q_{PH,p}$ are respectively the quantity of all produce of producer *p* after production and after post-harvest, as indicated by the producer.[29] C_i is the damage coefficient for category *i* (where the total number of categories are I), and $QC_{iPH,p}$ is the quantity in each category after post-harvest. $V_{Prod,p}$ and $V_{PH,p}$ are respectively the value of all produce after production and after post-harvest as given by the multiplication of respectively $Q_{Prod,p}$ and $Q_{PH,p}$ by an ideal price $\bar{P}_{ideal,p}$. $\bar{P}_{ideal,p}$ is the average sale price for an ideal product and $\bar{P}_{Ci,p}$ is the sample average sale price for a product in category *i.*[30] The difference in quantities or values (the first terms of equation 1 and 2) provide us with the total quantity or value lost between production and post-harvest activities; the second terms provide us with information on the quality degradation.

quality at the time of the survey, assuming stationarity is a good approximation of the price for the specific ideal attributes.

[29] Note that producers are not asked about the loss they incurred, as in the S-method, but about the amount they harvested and the amount they retain (to be either sold or consumed) after the post-harvest activities.

[30] By calculating the difference between the average ideal price and the actual price at one specific point in time, we get rid of the time-constant market conditions and are left with the quality differences. This stationarity assumption makes “ideal price” a good approximation of the price for a produce with ideal attributes.

At the middleman level, the quantity and quality degradation in weight ($WeightLoss_m$) and in value ($ValueLoss_m$) for middlemen m are given by eq. 3 and 4, respectively:

$$WeightLoss_m = WeightTotLoss_m + \sum_{i=1}^{I} C_i * (QC_{iPurchase,m} - QC_{iSale,m}) \quad (3)$$

$$ValueLoss_m = ValueTotLoss_m + \sum_{i=1}^{I} (\bar{P}_{ideal,m} - \bar{P}_{Ci,m}) * (QC_{iPurchase,m} - QC_{iSale,m}) \quad (4)$$

where C_i is the same damage coefficient as in the producers' survey, and $\bar{P}_{ideal,m}$ and $\bar{P}_{Ci,m}$ are the average sale price for an ideal product and sale price for a product in category i at the middlemen level, and $QC_{iSale,m}$ and $QC_{iPurchase,m}$ are the quantities in each category at purchase and at sale. To get the full quantity and quality degradation measure, we add the weight (or value) of the quantity that was totally lost, $WeightTotLost_m$or $ValueTotLost_m$, i.e., product that completely disappeared from the value chain. These figures are ideally obtained from the difference between the total purchase and total sales within a given period. In practice, middlemen are often unable to indicate these exact quantities, as the purchased crop is mixed with product in storage (see Table 3.A1 in the appendix).

Attribute method

The "attribute method" (A-method) is based on the evaluation of a crop according to inferior visual, tactile, and olfactory product characteristics. These attributes are identified prior to the survey implementation and in collaboration with commodity experts, local experts, and value chain actors. In addition, an extensive pilot was implemented to validate the attributes.[31] The number of attributes varies between 10 and 14, according to the commodity and country. At the time of the survey, the producer evaluates his or her production and establishes the share of total production that is

[31] It is important to mention that in certain countries, the attributes are defined as legal standards for the specific commodity. More information on the survey method is available in Delgado, Schuster & Torero (2017).

affected by the inferior damage attributes, both after production and after post-harvest.[32] Middlemen evaluate their product from the previous month at both purchase and sale. The producer and the middlemen declare how much their respective buyers punish them for inferior product attributes by paying a lower price. The price punishment information for each product attribute is used to estimate the value loss.

At the producer level, the quantity and quality degradation in weight ($WeightLoss_P$) and in value ($ValueLoss_P$) for producer *p* are given by eq. 5 and 6, respectively:

$$WeightLoss_p = \left(Q_{Prod,p} - Q_{PH,p} \right) + \sum_{j=1}^{J} a_{j,p} * Q_{PH,p} \tag{5}$$

$$ValueLoss_p = \left(V_{Prod,p} - V_{PH,p} \right) + \sum_{j=1}^{J} \overline{Pa}_{j,p} * Q_{PH,p} \tag{6}$$

where $Q_{Prod,p}$ and $Q_{PH,p}$ are respectively the quantity of all produce after production and after post-harvest for producer *p*, and $a_{j,p}$ is the share of product affected by damage attribute j. As in the C method, $V_{PH,p}$ and $V_{Prod,p}$ are the value of all produce after production and after post-harvest, respectively. The multiplication of $Q_{Prod,p}$ and $Q_{PH,p}$ by the ideal price $\bar{P}_{ideal}$. $\overline{Pa}_{j,p}$, respectively, is the average price punishment for an inferior product attribute at sale. This is obtained from the difference in the typical market price of the product at the producer level and the lower producer-level price given a specific damage. While the first terms of eq. 5 and 6 provide us with the total quantity or value lost (quantity degradation) between production and post-harvest, the second terms provide us with the quantity affected by a loss (quality degradation).

[32] In other words, a producer defines the percentage of its produce that is rotten, swollen, too pale, deformed, acid smelling, broken, too small, has an uncommon texture, among others.

At the middleman level, the quantity and quality degradation in weight ($WeightLoss_m$) and in value ($ValueLoss_m$) for middlemen m are given by eq. 7 and 8, respectively:

$$WeightLoss_m = WeightTotLoss_m + \sum_{aj=1}^{J}(Q_{Purchase,aj,m} - Q_{Sale,aj,m}) \quad (7)$$

$$ValueLoss_m = ValueTotLoss_m + \sum_{aj=1}^{J}(V_{Purchase,aj,m} - V_{Sale,aj,m}) \quad (8)$$

where $WeightTotLost_m$ and $ValueTotLost_m$ are the weight and value of the quantity that was totally lost, i.e., quantity degradation that completely disappeared from the value chain (as in equation 3 and 4). $Q_{Purchase,aj,m}$ and $Q_{Sale,aj,m}$ are the quantities in each attribute sold and purchased with a certain damage attribute by middleman m. $V_{Purchase,aj,m}$ and $V_{Sale,aj,m}$ are the values at sales and purchase that are lost due to a damage attribute and are obtained by multiplying the previous quantities ($Q_{Purchase,aj,m}$ and $Q_{Sale,aj,m}$) by an average price punishment at purchase and sale, obtained from the difference in the typical middlemen-level market price of the product and the lower price given a specific damage.

Price method

The "price method" (P-method) is based on the reasoning that higher (or lower) values of a commodity reflect higher (or lower) quality. A decrease in price, all else equal, is thus a proxy for a deterioration in quality.[33] Data regarding producers' and middlemen's ideal sale value are used and

[33] It is important to mention that the ideal prices do reflect the market conditions and quality the year the survey was conducted for the specific sub-national geographical location. Also, the actual price paid or received that year reflects the same market conditions and quality for the same sub-national geographical location. In our approach, we calculate the difference between the average ideal price (incorporating market structure) and the actual price given the specific quality at one specific point in time (which also incorporates market structure), thus getting rid of the time constant market conditions. What is left are the quality differences. This stationarity assumption makes "ideal price" a good approximation of the price for a produce with ideal attributes.

compared to the value of their actual production, purchase, and sale. The following equation provide us with the total loss at the producer level:

$$ValueLoss_p = V_{ideal,p} - V_{PH,p} \quad (9)$$

where *p* indicates the producer, $V_{ideal,p}$ is the ideal value of a producers' production and is obtained by multiplying producers' production by the average ideal sale price. $V_{PH,p}$ is the total value of the producers' production after post-harvest, as assessed by the farmer himself. The value loss can be translated into a weight loss at the producer level by dividing it by the average ideal sale price:

$$WeightLoss_p = \frac{ValueLoss_p}{\bar{P}_{ideal,p}} \quad (10)$$

For the middlemen, the estimated quality degradation is given by the difference between the weight (or value) affected by loss at sale (first term equation 11 or 12) and the weight (or value) affected by loss at purchase (second term equation 11 or 12) to estimate the total weight (or value) affected by loss at this level of the chain. The weight (or value) affected by the loss at purchase or sale is estimated by taking the difference between the sale (purchase) value of an ideal product and the actual sale (purchase) value.

We add the weight (or value) of the quantity that was totally lost, $WeightTotLost_m$ or $ValueTotLost_m$, i.e., product that completely disappeared from the value chain and thus represents the quantity degradation (as in equations 3, 4, 7 and 8). This translates into the following two equations:

$$ValueLoss_m = \left(V_{Sale;ideal,m} - V_{Sale;actual,m}\right) - \left(V_{Purchase;ideal,m} - V_{Purchase;actual,m}\right) + ValueTotLoss_m \quad (11)$$

$$WeightLoss_m = \left(Q_{Sale;ideal,m} - Q_{Sale;actual,m}\right) - \left(Q_{Purchase;ideal,m} - Q_{Purchase;actual,m}\right) + WeightTotLoss_m \quad (12)$$

3.5 Data

We have developed detailed surveys across the different components of the food value chain and specific to different commodities (more extensive information on the survey method is available in Delgado, Schuster & Torero, 2017). These surveys allow us to quantify the extent of food loss across the value chain before consumption using *consistent* approaches that are comparable across commodities and regions. They also enable us to characterize the nature of food loss, specifically the production stages and the particular processes during which loss is incurred. The richness of the data allows us to provide estimates using the four methodologies.

The producer survey has three modules. The first module asks about the quantity of the crop left in the field, the quantity totally lost in pre-harvest, the total production harvested, and the qualities, attributes, and prices of the harvest.[34] The second module asks about the quantity of affected (quality degradation)[35] and the quantity totally lost (quantity degradation)[36] during post-harvest activities (e.g., winnowing, threshing, grading, transporting, packaging, etc.). The third module records the destination of the product (i.e., for consumption, sale, donation, etc.), as well as the damage attributes and categories for the quantity for sale.

The middleman survey has three modules. The first two modules ask about the quantity, quality, and attributes of the total product respectively purchased and sold in a defined period (depending on the country). The third module asks about the quantity of product affected by quality deterioration and total loss for each crop during post-harvest processing activities.

[34] Quality attributes were identified for each country and commodity prior to the survey implementation and in collaboration with commodity experts of the CGIAR centers. We worked with CIMMYT for wheat and maize, CIAT for beans, ICARDA for teff, and CIP for potatoes. All the centers specialize in the specific commodity attributes and value chain actors. A pilot survey was then implemented to validate and eventually adjust the attributes.

[35] Affected product: Product with lower quality, but can still be used.

[36] Totally lost: Product that is completely lost and cannot be used.

The processor survey has two modules. The first module asks about the quantity, quality, and attributes of the total product purchased in a specific time-period (depending on the country). The second module asks about the specific steps required to obtain the final product for consumption.

Each of the three surveys includes inquiries about aggregate self-reported measures of loss. We ask producers, middlemen, and processors about the quantities (and the corresponding monetary values) of crops discarded during their activities. We also include a disaggregated description of the stages and processes at which losses occurs. Within each survey, we categorize crop damage and crop attributes for each crop and country. We created a damage coefficient based on degrees of quality. Each crop has its own damage coefficient, determined using international classification in collaboration with local experts.[37]

In the attributes section of each survey, producers, middlemen, and processors are asked to evaluate the crops' physical or chemical characteristics. These characteristics are specific to each country and crop, and were identified in collaboration with value chain actors and commodity experts. In our surveys, the damage to each crop is determined by texture, size, moisture, the presence of fungus or insects, among others.[38] We confirm through expert consultations and in the different markets the price punishment that each of these types of crop damage entails.

[37] Details regarding the classification are available upon request.

[38] For example, in the maize value chain in Honduras and Guatemala, producers, middlemen, and processors were asked to evaluate the percentage of crop that was chopped, contained weevil, was small, smelled acidic or like fumigation, had a rough texture, was swollen, was rotten, had fungal damage, had stains, or was broken.

Value chains and descriptive statistics

In all the countries, we chose our sample based on a pre-census of the producers who have produced the specific crop of interest in the last cropping season; this formed our baseline. In Ecuador, for instance, every person consumes around 30 kg of potatoes per year (MAGAP, 2014). Ecuador produces 397,521 tons of potatoes annually, with the province of Carchi producing 36 percent of the national volume (ESPAC, 2015). Our surveys in Ecuador were organized between June and October 2016 for each segment of the potato value chain. All producers in the survey came from the province of El Carchi, while the middlemen were from the provinces of El Carchi, Imbabura, and Pichincha, and the processors were from the province of Pichincha.

Peru's annual consumption of potatoes is around 89 kg per person (MINAGRI, 2016). In 2014, 318,380 hectares were used to plant potatoes and 4,704,987 metric tons of potatoes were produced (FAOSTAT, 2019). The departments of Junín and Ayacucho provide around 60 percent of the potatoes that go to the wholesale market in Lima (EMMSA, 2019). Our surveys in Peru were organized between September and December 2016 for each segment of the potato value chain. The producers in the survey were from the departments of Junín and Ayacucho, while the middlemen and processors were from the department of Lima.

Maize and beans form the fundamental basis of food security for much of the Central American population, and they contribute to household and national economies through employment and income generation. In Honduras, maize is one of the most important basic grains, but the domestic maize supply only covers 42 percent of the country's demand (SAG/UPEG, 2015). The annual consumption of maize in Honduras in 2013 was around 78 kg per person. The production of maize in 2014 was 609,312 metric tons over an area of 263,343 hectares (FAOSTAT, 2019). The three principal production departments of white maize in Honduras are Olancho, El Paraíso, and Comayagua. Beans are the second most important basic grain in Honduras, both in area planted and in production for consumption. In 2014, the annual consumption and production of beans in Honduras was 12 kg per person and 105,812 metric tons, respectively; an average of 132,659 hectares were planted with beans (FAOSTAT, 2019). The three principal production departments for beans in Honduras are Olancho, El Paraíso, and Yoro. Our surveys for Honduras were organized between July and September 2016 for each segment of the maize and bean value chains. The producers, middlemen, and processors in the survey were from the departments of Choluteca, Copan, El Paraiso, Francisco Morazán, Intibucá, La Paz, Lempira, Ocotepeque, Olancho, Santa Barbara, and Valle.

Table 3.1: Sample Size

	Ecuador	**Peru**	**Honduras**	**Guatemala**	**Ethiopia**	**China**
Producer	302	411	1209	1155	1203	1114
Middlemen	182	85	325	365	---	140
Processor	147	139	224	245	---	53
Total	**631**	**594**	**1758**	**1765**	**1203**	**1307**

Note: In the case of teff in Ethiopia, we only survey producers because most of the producers will bring their teff to millers who work on a fee-for-service basis, returning milled teff flour to the producers without any major intermediation of middlemen or processors.

In Guatemala, the area cultivated to maize was 871,593 hectares with production reaching 1,847,214 metric tons in 2014. Per capita consumption in 2013 was around 87 kg per person per year (FAOSTAT, 2019). The three principal production departments of white maize in Guatemala are Petén (18.5 percent), Alta Verapaz (9.4 percent), and Jutiapa (7.3 percent) (MAGA, 2017). Beans are the second most important basic grain in Guatemala, both in area planted and in production for consumption. In 2014, the consumption of beans in Guatemala was 12 kg per person per year; area planted to beans covered an average of 250,414 hectares, with production at 235,029 metric tons (FAOSTAT, 2019). The three principal production departments for beans in Guatemala are Petén (27 percent), Jutiapa (13 percent), and Chiquimula (10 percent) (MAGA, 2017). Our surveys in Guatemala were organized between September and December 2016 for each segment of the maize and bean value chains. The producers, middlemen, and processors were from the departments of Chimaltenango, Escuintla, Guatemala, Quetzaltenango, Sacatepéquez, San Marcos, Sololá, and Totonicapán.

Teff is a major crop in Ethiopia in terms of both production and consumption. Teff is the dominant cereal crop for total area planted with 3,760,000 hectares in 2012/2013 (Crymes, 2015) and second only to corn in production and consumption with 3,769,000 metric tons of production (Crymes, 2015). According to Berhane, et al. (2012), based on national data from the Household Income, Consumption and Expenditure Survey (HICES, 2011) between 2001 and 2007, urban consumption of teff per capita was as high as 61 kg per year, while rural consumption was 20 kg per capita per year. Amhara and Oromia together accounted for 84 and 86 percent of the total cultivated area and production in 2011, respectively. Our surveys in Ethiopia were organized between August and October 2016 in the zones of Oromia and Amhara. These surveys covered the producer chain only, since the teff value chain does not include important middlemen or processors.

Wheat is China's second most important food crop after rice. In 2014, China produced about 120 million metric tons of wheat each year on approximately 24 million hectares of land (FAOSTAT, 2019). In 2013, the annual consumption of wheat in China was around 63.1 kg per capita (FAOSTAT, 2019). Three northern provinces — Henan, Shandong, and Hebei — collectively account for over 50 percent of China's wheat output (China Statistical Yearbook, 2001). Our surveys in China were organized between August and October 2016 for each segment of the value chain. The producers, middlemen, and processors were from the provinces of Henan and Shandong.

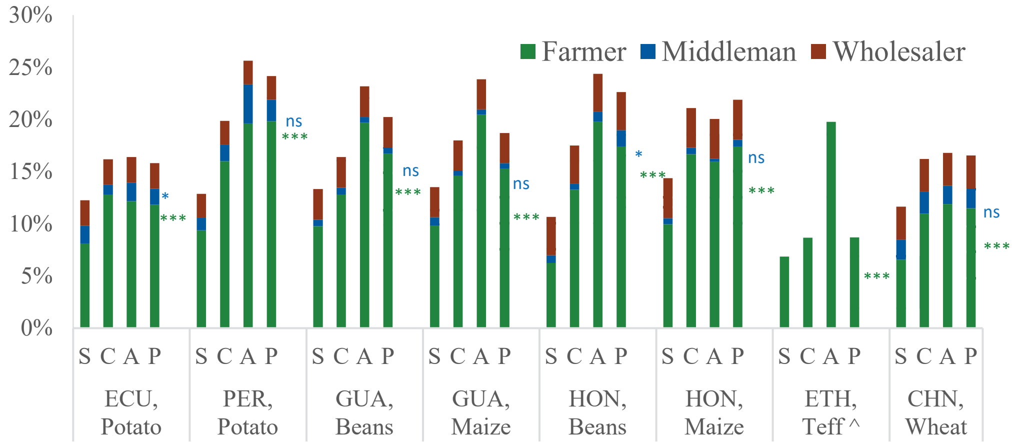
We adapted our instrument for the specifications of each crop and country. In a stratified random set-up, we sampled a moderate number of actors per segment in each country. Table 3.1 reports the sample size (N) of producers, middlemen, and processors in each country. Tables 3.2-3.4 respectively provide simple socio-demographic statistics of the sampled producers, middlemen, and processors for each different crop and country. The large majority of all sampled producers (around 90 percent) are male across all countries and value chains, and are between the ages of 45 and 50. On average, they are smallholder farmers, as they cultivate between 0.35 hectares (beans in Guatemala) and 3.5 hectares (potato in Ecuador) of land. Producers have mostly achieved primary education; only in Peru and China, almost half of all producers also completed secondary education. Middlemen tend to be slightly younger than farmers, and there are more women than men (with the exception of China, 40 percent of all middlemen are women). The large majority of all middlemen sell both in bulk and to end-users. Finally, while the age of the wholesaler is about 43 years, the gender of the wholesaler varies largely by crop and country. For beans and maize in Guatemala and Honduras, the wholesalers/transformers are mainly female; in the wheat and potato sector, wholesalers are predominantly male.

3.6 Results

Figure 3.4 shows loss levels at the producer, middlemen, and processor levels separately and alternatively for the four estimation methodologies (i.e., aggregated self-reported (S), category (C), attributes (A), and price method (P)). Some observations are discarded due to missing values and outliers.[39] Loss figures include both the quantitative degradation (i.e., product that completely disappeared from the value chain) and the quality degradation (i.e., the product affected by quality deterioration). Losses are alternatively expressed in weight and values, with the latter providing information regarding the economic damage caused by them.

[39] We use ‘‘winsorizing” technique, replacing extreme outliers beyond the 99th percentile with missing values under the assumption that all extreme values are due to measurement error.

a) Food Loss in Percentage of Total Production (Volume)



b) Food Loss in Percentage of Total Value of Production (USD)

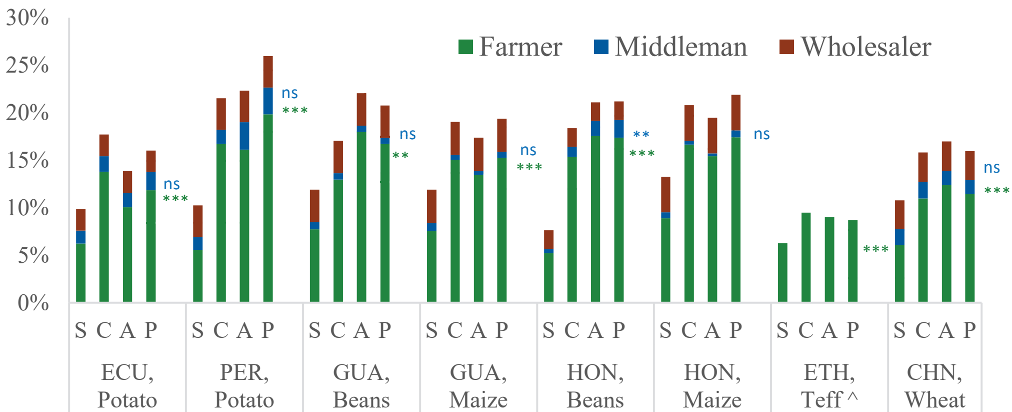


Figure 3.4: Quantitative and Qualitative Food Loss along the Value Chain, Estimated Using Four Methodologies

Note: S= Aggregate self-reported method; C= Category method; A= Attribute method; P= Price method. Significant differences from one-way ANOVA comparing the four group means – by farmer or middleman level – indicated with *p < 0.10, **p < 0.05, ***p < 0.01 , 'ns' p ≥ 0.10. Loss estimation at the wholesale level comes from the S-method only, so no ANOVA comparison is carried out.

^For teff in Ethiopia, data covered the producer chain only, given that there are no important middlemen and processors in this value chain.

As shown in Figure 3.4, loss figures across all value chains fluctuate between 6 and 25 percent of the total production and total value of production. Loss figures are consistently largest at the producer level and smallest at the middleman level. Across the different estimation methodologies, loss at the producer level represents between 60 and 80 percent of the total value chain loss, while the average loss at the middleman and processor levels is around 7 and 19 percent, respectively. At the processor level, losses fluctuate between 2 and 3 percent. It is important to mention that these losses do not include yield gaps, which could vary between 50 and 80 percent. These yield gaps represent the distance to the production possibility frontier, defined as the distance of the sale quantities or prices and the frontier.

Percentage losses expressed in value tend to be slightly smaller than those expressed in weight for the S-method. This difference is prominent in the A-method, indicating that the market does not seem to penalize some quality degradation at the farm level. The category method leads to results that are more similar in terms of weight and value loss.

Differences across methodologies are salient, especially at the producer level. Analysis of Variance (ANOVA) finds significant across-group variation of loss figures at the producer level for all 8 value chains at $p < .01$ level (Figure 3.4).[40] Except for the bean value chain in Honduras, loss figures across methodologies are similar and not statistically different for middlemen. ANOVA results are similar when quantity loss and quality degradation are reported in weight or values. The skewness of the loss figures (Table 3.A2 in the appendix) reveals that the left-side tail ("no loss") seems consistently higher for the S-method than the C-, A- and P-methods.

[40] The skewness of the loss figures as estimated by the different measurement methods is reported in Table 3.A2 of the appendix.

Table 3.2: Producer Characteristics

Variable name			Ecuador: potato (N = 302)		Peru: potato (N = 411)		Guatemala: beans (N = 450)		Guatemala: maize (N = 922)		Honduras: beans (N = 685)		Honduras: maize (N = 1024)		Ethiopia: teff (N = 1203)		China: wheat (N = 1114)	
			mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
Socio-economic	Gender (male)		92.72%	0.26	80.05%	0.40	87.56%	0.33	87.42%	0.33	95.04%	0.22	95.02%	0.22	94.18%	0.23	83.93%	0.37
	Age (years)		50.15	13.97	44.36	14.02	48.75	15.03	50.23	15.01	47.78	14.47	48.52	15.07	44.21	11.43	53.85	10.90
	Education	no education	1.99%	0.14	3.89%	0.19	29.11%	0.45	30.91%	0.46	17.22%	0.38	19.14%	0.39	37%	0.48	6%	0.24
		primary	73.84%	0.44	37.47%	0.48	65.33%	0.48	58.79%	0.49	79.42%	0.40	77.64%	0.42	39.32%	0.49	24.60%	0.43
		secondary	11.92%	0.32	47.93%	0.50	3.78%	0.19	4.23%	0.20	2.48%	0.16	2.34%	0.15	20.20%	0.40	48.56%	0.50
		>secondary	12.25%	0.33	10.71%	0.31	2.00%	0.14	6.07%	0.24	0.88%	0.09	0.88%	0.09	0.25%	0.05	20.38%	0.40
Production	Quantity produced last harvest (Kg)		49,099	105,760	70,310	301,281	145	256	1,023	1,781	629	1,171	2,251	14,406	1,479	1,404	9,260	39,369
	Area cultivated (in hectares)		3.48	5.91	2.82	7.78	0.35	0.76	0.52	1.10	1.09	1.47	1.45	3.14	1.23	1.13	1.47	6.45

To determine which groups differed from each other at the producer and middleman level, we perform a pairwise comparisons of means. Results are reported in Table 3.5. At the farm-stage level, the estimation results from the C-, A-, and P-methods tend to converge, but the aggregate self-reported method systematically reports statistically different lower loss figures. These gaps are largest in the beans value chain in Honduras and the potato value chain in Peru, in which self-reported loss estimates are between 10 and 15 percentage points lower than those estimated using any of the other methods. Some significant differences also exist across the C-, A-, and P-methods, but results are less consistent across countries and value chains.

Table 3.3: Middleman Characteristics

Variable name		Ecuador: potato (N = 182)		Peru: potato (N = 85)		Guatemala: beans (N = 169)		Guatemala: maize (N = 156)		Honduras: beans (N = 248)		Honduras: maize (N = 129)		China: wheat (N = 140)	
		mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
Gender (male)		56,59%	0,50	57,65%	0,50	55,62%	0,50	69,23%	0,46	56,45%	0,50	60,47%	0,49	85,00%	0,36
Age (years)		48,85	11,19	45,66	10,33	42,04	13,34	45,38	14,41	44,34	13,41	46,30	13,23	44,15	8,15
Type of business	intermediary	56,59%	0,50	0,00%	0,00	4,14%	0,20	3,21%	0,18	7,26%	0,26	13,95%	0,35	17,86%	0,38
	wholesaler	30,77%	0,46	97,65%	0,15	95,86%	0,20	96,79%	0,18	92,74%	0,26	86,05%	0,35	82,14%	0,38
	retailer	12,64%	0,33	2,35%	0,15										

Table 3.4: Processor Characteristics

Variable name	Ecuador: potato (N = 182)		Peru: potato (N = 153)		Guatemala: beans (N = 120)		Guatemala: maize (N = 104)		Honduras: beans (N = 121)		Honduras: maize (N = 124)		China: wheat (N = 53)	
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
Gender (male)	53,06%	0,50	80,39%	0,40	19,17%	0,40	12,50%	0,33	15,70%	0,37	8,87%	0,29	94,34%	0,23
Age (years)	43,93	13,15	42,16	10,14	41,55	11,82	38,94	11,74	44,17	12,83	46,36	13,53	46,68	8,86
Number of sub-product transformations	1,08	0,28	1,01	0,08	1,01	0,09	1,08	0,27	1,35	0,48	1,23	0,43	1,21	0,41

Note: In the case of teff in Ethiopia, we only survey producers because most of the producers will bring their teff to millers who work on a fee-for-service basis, returning milled teff flour to the producers without any major intermediation of middlemen or processors.

Table 3.5: Pairwise Comparisons of Means – Producer and Middleman Level

a) Producer Level: Food Loss in % of Total Production (Volume)

	Ecuador, Potato	Peru, Potato	Guatemala, Beans	Guatemala, Maize	Honduras, Beans	Honduras, Maize	Ethiopia, Teff	China, Wheat
C vs S	0.047 ***	0.066 ***	0.030 *	0.047 ***	0.070 ***	0.067 ***	0.018 *	0.044 ***
A vs S	0.041 **	0.102 ***	0.099 ***	0.106 ***	0.135 ***	0.060 ***	0.129 ***	0.053 ***
P vs S	0.037 **	0.105 ***	0.069 ***	0.054 ***	0.111 ***	0.075 ***	0.018 *	0.049 ***
A vs C	-0.006	0.036 **	0.069 ***	0.059 ***	0.065 ***	-0.007	0.111 ***	0.009
P vs C	-0.010	0.039 **	0.039 *	0.007	0.041 ***	0.007	0.000	0.005
P vs A	-0.003	0.002	-0.029 *	-0.052 ***	-0.024	0.015	-0.111 ***	-0.004

b) Producer Level: Food Loss in % of Total Value of Production (USD)

	Ecuador, Potato	Peru, Potato	Guatemala, Beans	Guatemala, Maize	Honduras, Beans	Honduras, Maize	Ethiopia, Teff	China, Wheat
S vs C	0.076 ***	0.111 ***	0.052 ***	0.075 ***	0.101 ***	0.078 ***	0.032 ***	0.049 ***
S vs A	0.038 ***	0.105 ***	0.103 ***	0.058 ***	0.123 ***	0.065 ***	0.028 ***	0.063 ***
S vs P	0.056 ***	0.143 ***	0.090 ***	0.077 ***	0.122 ***	0.085 ***	0.024 ***	0.054 ***
C vs A	-0.038 **	-0.006	0.050 ***	-0.016 *	0.022	-0.012	-0.005	0.014
C vs P	-0.019	0.031 **	0.038 ***	0.002	0.021	0.008	-0.008	0.005
A vs P	0.018	0.037	-0.013	0.019 **	-0.002	0.020 *	-0.003	-0.009

c) Middleman Level: Food Loss in % of Total Production (Volume)

	Ecuador, Potato	Peru, Potato	Guatemala, Beans	Guatemala, Maize	Honduras, Beans	Honduras, Maize	China, Wheat
S vs C	-0.008 *	0.004	0.000	-0.003	-0.002	0.000	0.002
S vs A	0.001	0.025	0.000	-0.003	0.002	-0.003	-0.002
S vs P	-0.002	0.008	-0.001	-0.003	0.008	0.000	0.000
C vs A	0.009 *	0.021	-0.001	0.000	0.004	-0.003	-0.003
C vs P	0.006	0.005	-0.001	0.000	0.010 *	0.001	-0.002
A vs P	-0.003	-0.017	0.000	0.001	0.006	0.004	0.002

d) **Middleman Level: Food Loss in % of Total Value of Production (USD)**

	Ecuador, Potato	Peru, Potato	Guatemala, Beans	Guatemala, Maize	Honduras, Beans	Honduras, Maize	China, Wheat
S vs C	0.003	0.002	-0.001	-0.003	0.006	-0.002	0.002
S vs A	0.002	0.016	-0.001	-0.004	0.011	-0.003	-0.001
S vs P	0.005	0.015	-0.002	-0.002	0.014 **	0.001	-0.002
C vs A	-0.001	0.014	0.000	-0.001	0.005	-0.001	-0.003
C vs P	0.003	0.013	0.000	0.001	0.007	0.003	-0.004
A vs P	0.004	-0.001	0.000	0.002	0.002	0.004	-0.001

Note: S= Aggregate self-reported method, C= Category method; A= Attribute method; P= Price method

Differences in mean between the food loss estimation methods are reported. Significant differences from Tukey post-hoc comparison of means test indicated with *p < 0.10, **p < 0.05, ***p < 0.01

Losses at the producer level can be mainly attributed to the pre-harvest stage (on average 4.13 percent of the total production volume and 4.19 percent of the total production value) and less to the post-harvest stage (on average 8.30 percent of the total production volume and 6.82 percent of the total production value) or quantities left in the field (less than 1 percent). The S-methods systematically report lower loss figures than the C-, A-, and P-methods across both the pre- and post-harvest stages at the producer level (Table 3.A3 in the appendix).

Causes of food losses

Figure 3.5 presents the major reasons producers cited for their pre-harvest loss, their crop left in the field, and their post-harvest loss. In the specific case of pre-harvest loss, the major reasons reported by producers included pests and diseases and lack of rainfall; teff was the exception, with lack of rainfall being the major reason reported for pre-harvest loss. When looking at the produce left in the field, the major reason for the loss is a lack of appropriate harvesting techniques. Potatoes in Ecuador was the exception, with small or poor-quality potatoes being the major reason reported for produce left in the field. Both in Ecuador and Peru, worker shortages or excessive labor costs are important limiting factors. In China, weather conditions are one of the main reasons why produce is left in the field. The main causes of post-harvest losses, with the exception of China and Ethiopia, are damage to crops done by workers during harvesting or sorting, because of their lack of training and experience.[41] In China, mechanical damage is most prevalent, followed by damage caused by laborers during harvesting. In Ethiopia, most post-harvest losses occur because produce is blown away or spilled. Other causes include poor storage and laborer damage.

It is important to mention that causes such as cost of labor or low market price are endogenous to the specific commodity and market structure location. Therefore, this needs to be taken into consideration when interpreting and comparing the results across commodities and countries.

[41] For further details on determinants of food losses, see Delgado et al. (2021a).

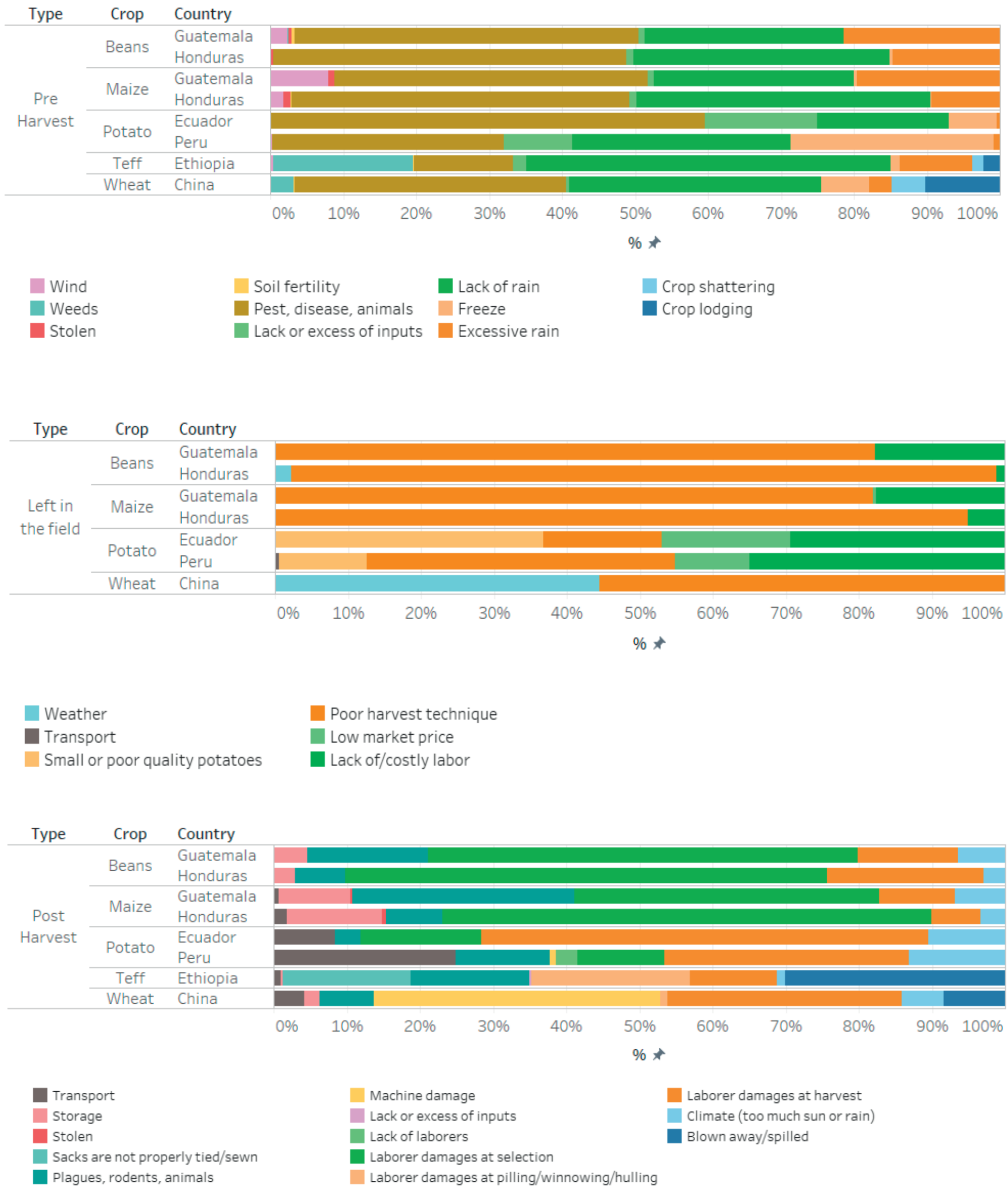


Figure 3.5: Self-Reported Causes of Losses

3.7 Conclusions

Addressing food loss across the value chain requires a common understanding of the concept by all actors. A collaborative effort is also required to collect better micro data across the value chain and of different commodities and contexts. As stated earlier, food loss has been defined in many ways, and there is disagreement over proper terminology and methodology to measure it.

We address this existing measurement gap by developing and testing three new methodologies that aim to reduce measurement error and assess the magnitude, causes and costs of food loss, as well as the stages across the value chain where losses occur. The methods account for food loss from pre-harvest to product distribution and include measurement of both quantity loss and quality deterioration. Following a framework similar to the one used by de Mel et al. (2009), we establish a benchmark based on observations and food loss data measured on the farm. Every effort has been made to be as detailed as possible on the attributes and categories identified in each of the commodity and country, and to establish consistency across the three new methodologies. We apply them to producers, middlemen, and processors in seven staple food value chains in five developing countries.

The estimation results from the three new methods are close to each other with respect to the aggregate self-reported method, which shows systematically lower loss figures. This is evidence that we are converging on truth, but there are still some statistical differences among the three methodologies. As a result, which method to use at the end will depend on the specific context in the field, such as which information can be collected at the lowest cost and with the lowest measurement error. Our figures are larger than those recently obtained by Kaminski and Christiansen (2014) and Minten et al. (2016a and b) due to the inclusion of qualitative loss and quality and quantity effects. Despite this, the most important value of the proposed methodology is that it allows us to break down the losses at the level of farmer, middleman, and processor and incorporate both concept of quantitative loss (i.e., the product entirely disappeared from the value chain) and qualitative loss (i.e., the product was affected by quality deteriorations).

Loss figures are consistently largest at the producer level and smallest at the middleman level. Across the different estimation methodologies, loss at the producer level represents between 60 and 80 percent of the total value chain loss, while the average loss at the middleman and processor levels is at around 7 and 19 percent, respectively.

Micro-causes such as the presence of pests, lack of rainfall, and lack of appropriate post-harvest technologies are behind the losses in our study. Lack of appropriate storage facilities (FAO, 2011; Liu, 2014) and efficient transport systems (Rosegrant e.at., 2015) are also important micro-causes of food loss. Other causes ranging from crop variety choices and pre-harvest pests to processing and retail decisions are also notable.

Micro-causes can be linked to broader meso-causes. Analyzing the factors affecting food loss at the micro-, meso-, and macro-level can help identify effective reduction interventions. Studies point to credit constraints as one of the main bottlenecks to technology adoption to reduce food loss (HLPE, 2014). Others point to the importance of education (Kaminski and Christiaensen, 2014), contractual practices (Parfitt et al., 2010), and the growing need to improve infrastructure, particularly in rural areas.[42] It is clear that further research is needed to identify the determinants behind the level of losses identified, controlling for the heterogeneity among farmer and production characteristics. For example, it is essential to understand the

[42] Rosegrant et al. (2015) finds that electricity, roads, and railways have an important role in PHL reduction. After getting the estimates of infrastructure on PHL reductions, the study uses the cost of infrastructure development to estimate a number of investment scenarios. These scenarios were later implemented in the IMPACT global food supply and demand model (IFPRI) to simulate the impact of PHL reduction on food prices, security, consumer and producer surplus, net welfare gains, and benefit cost ratios to the investment. Overall, it was found that reduction in PHL is not a low-cost alternative, but rather it requires large investment and is complementary to long-term investments to achieve food security.

role of demographic characteristics of the farmers, their education, producer experience, gender, production factors (access to technology, agricultural assets, and infrastructure), and geographic and climatic factors.

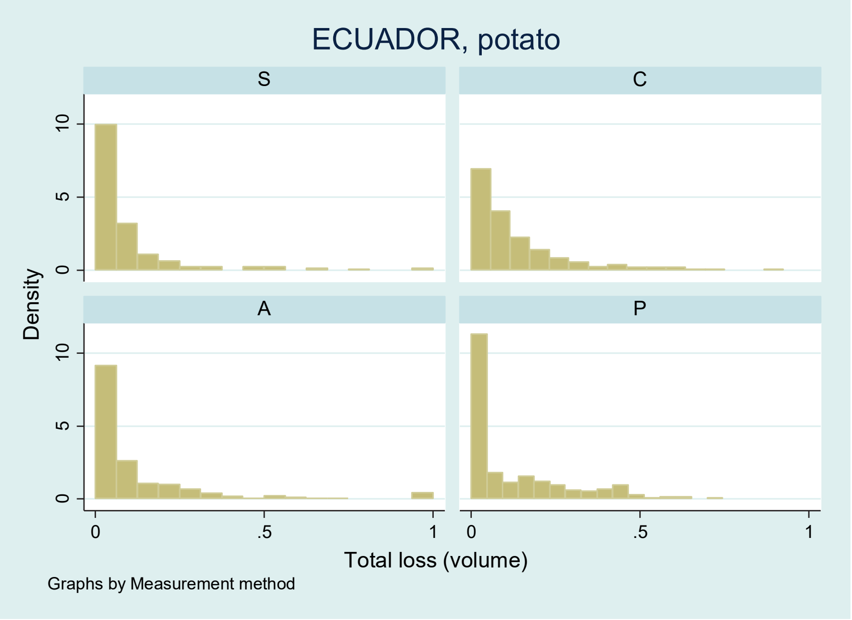
Policymakers need to work with value chain actors to translate these insights into action. They should focus on collecting evidence-based and consistent information across the value chain and ensure that public and private sector investments facilitate food loss reduction, specifically targeting hotspots. Finally, they should identify the main causes of food loss in specific stages of the value chain based on methodologies proposed by this paper.

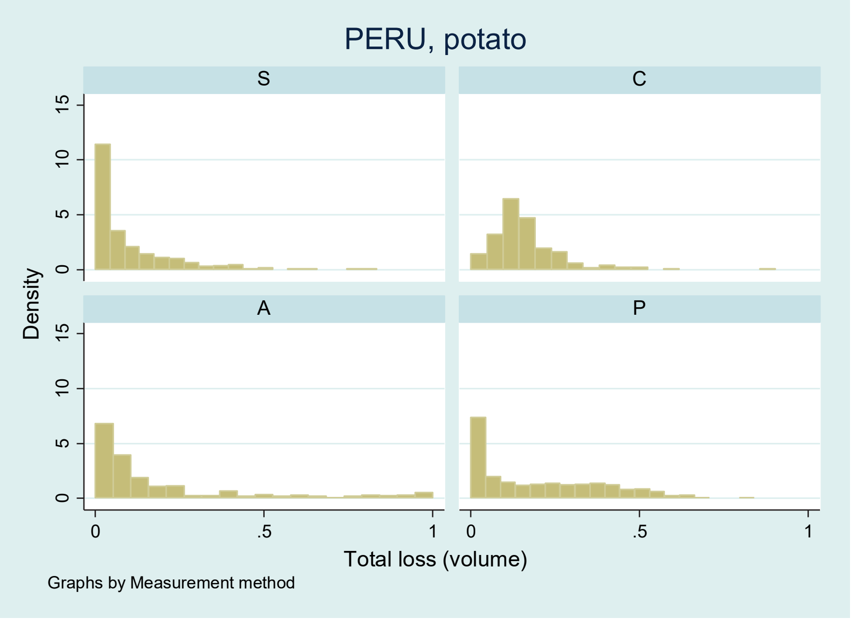
Appendix

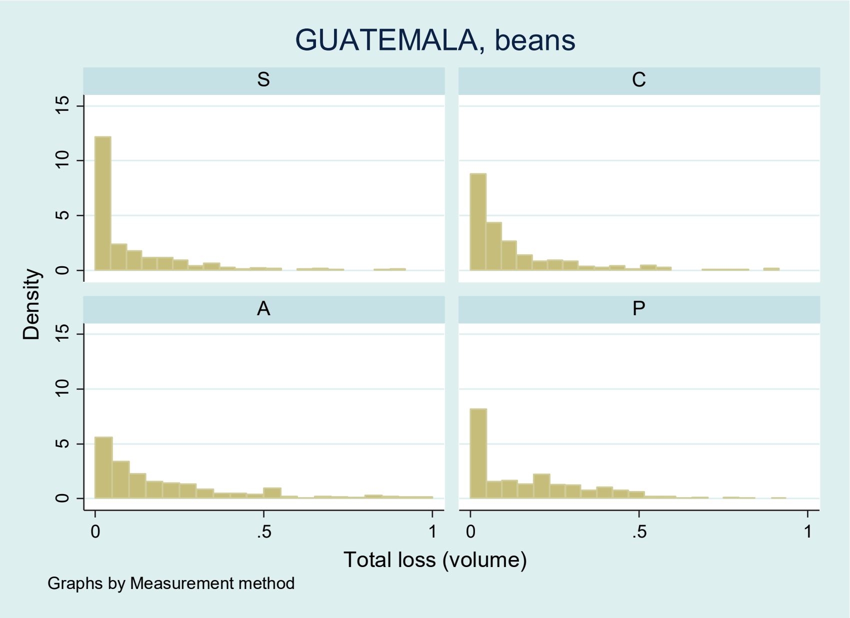
Table 3.A1: Survey Questions to Estimate Food Losses with the Aggregate Self-Reported Method

		Sum of survey questions: 'In the last planting season.... '
PRODUCER	**Loss expressed in weight**	a) what is the quantity of your harvest that was damaged (previous to post-harvest activities)? b) what is the quantity of good product that was not harvested (left in the field)? c) what is the quantity totally lost during post-harvest activities? d) what is the quantity damaged during post-harvest activities?
	Loss expressed in value	a) what is the value of your harvest that was damaged (previous to post-harvest activities)? b) what is the value of the quantity of good product that was not harvested (left in the field)? c) what is the value of your product totally lost during post-harvest activities? d) what is the value of your product damaged during post-harvest activities?
		Sum of the survey questions: 'Last month, and between the moment of purchase and sales of your product...'
MIDDLEMEN	**Loss expressed in weight**	a) Was is the quantity of your total purchase that got damaged during each of your post-harvest activities? b) Was is the quantity of your total purchase that got totally lost during each of your post-harvest activities?
	Loss expressed in value	a) Was is the value of your total purchase that got damaged during each of your post-harvest activities? b) Was is the value of your total purchase that got totally lost during each of your post-harvest activities?
		Sum of the survey questions: 'Last month, and between the moment of purchase and sales of your product...'
PROCESSOR	**Loss expressed in weight**	a) Was is the quantity of your total purchase that got damaged during each of your transformation activities? b) Was is the quantity of your total purchase that got totally lost during each of your transformation activities?
	Loss expressed in value	a) Was is the value of your total purchase that got damaged during each of your transformation activities? b) Was is the value of your total purchase that got totally lost during each of your transformation activities?

Table 3.A2: Skewness of Food Loss (in Volume), by Country and Measurement Method






GUATEMALA, beans
S
C
A
P
Density
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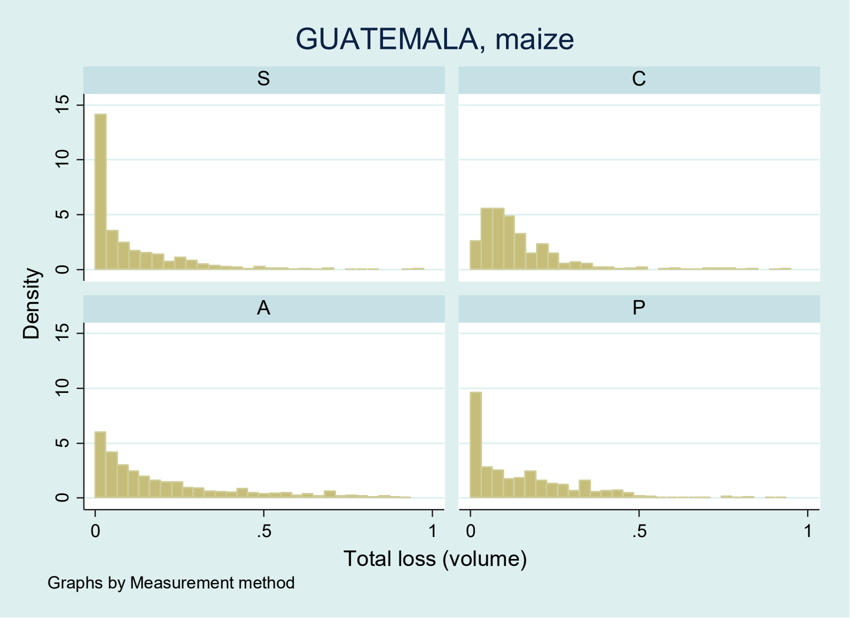
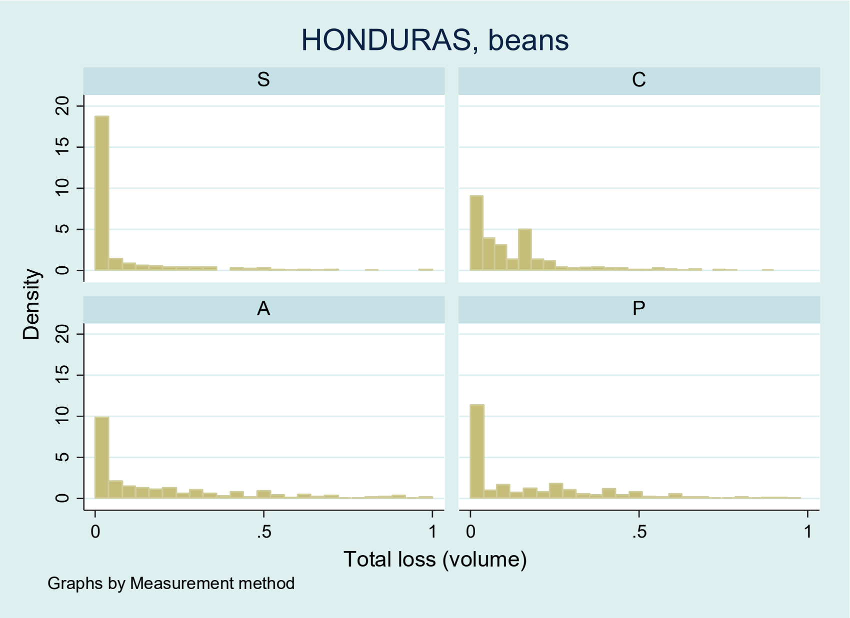
5
10
15
0
.5
1
Total loss (volume)
Graphs by Measurement method


GUATEMALA, maize
S
C
A
P
Density
0
5
10
15
0
.5
1
Total loss (volume)
Graphs by Measurement method


HONDURAS, beans
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Density
0
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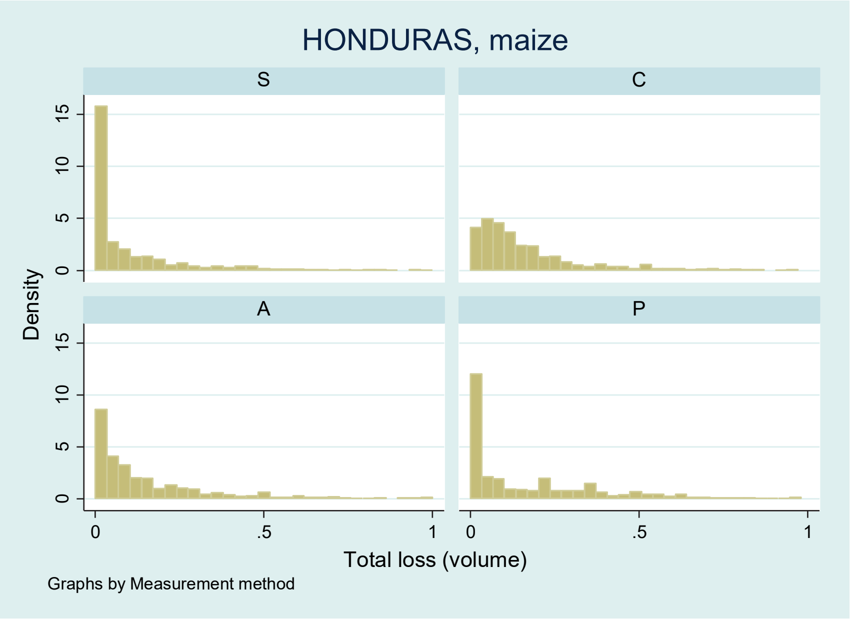
.5
1
Total loss (volume)
Graphs by Measurement method


HONDURAS, maize
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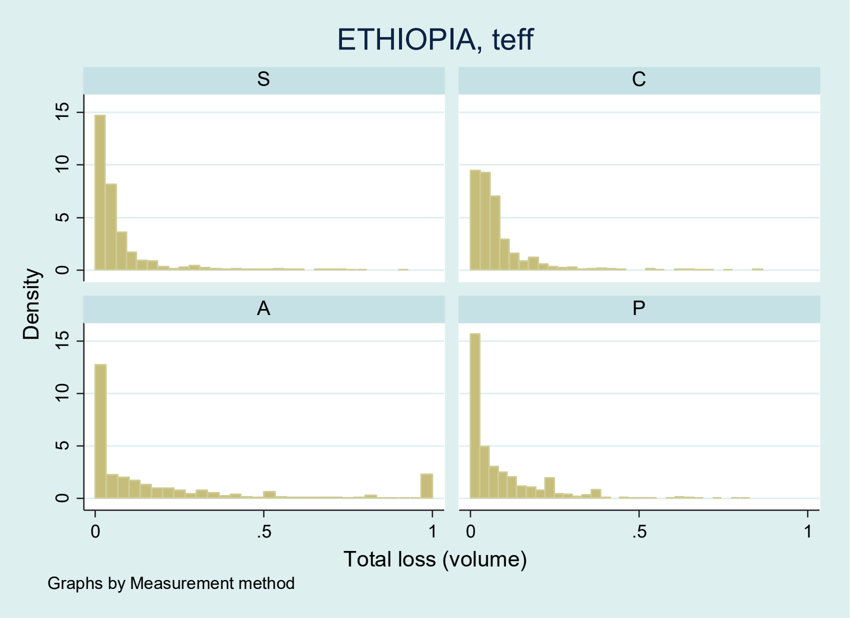
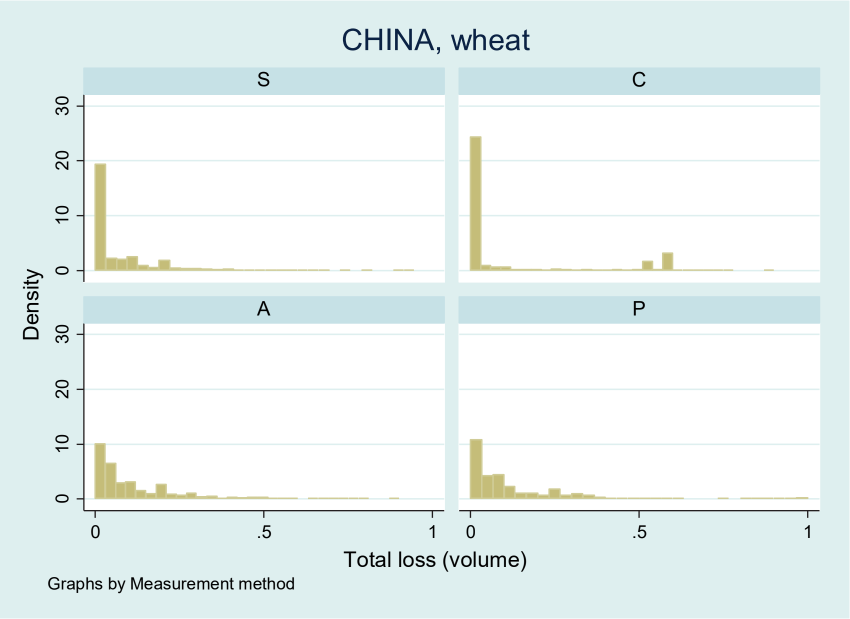
1
Total loss (volume)
Graphs by Measurement method

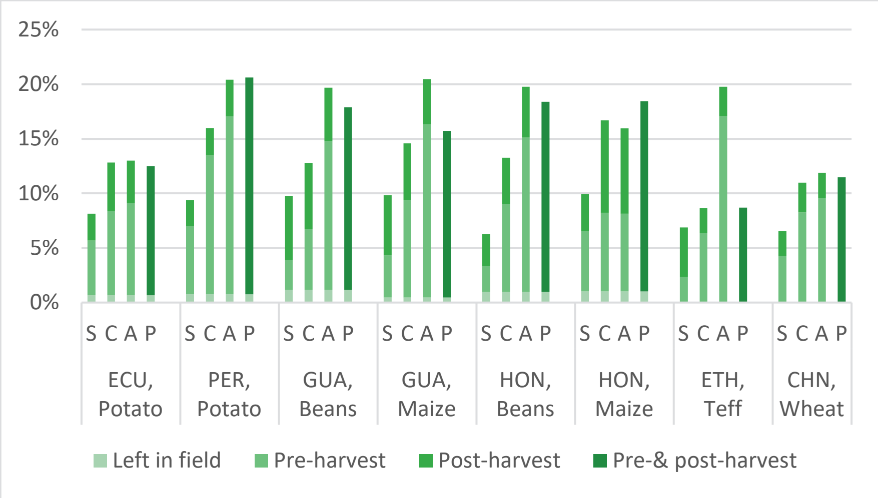




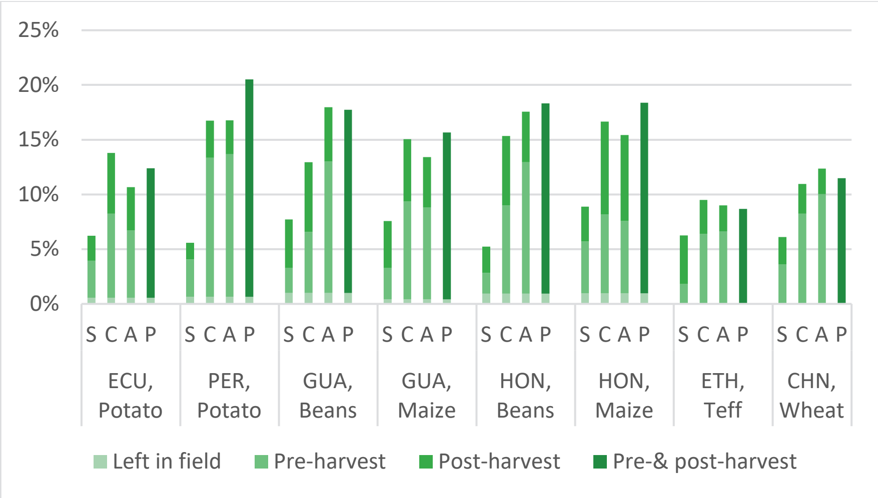
Note: The skewness of food loss in value is similar and is available upon request.

Table 3.A3: Food Loss at Farm Level, by Stage of Loss

a) Food Loss in Percentage of Total Production (Volume)



b) Food Loss in Percentage of Total Value of Production (USD)



Note: S= Aggregate self-reported method; C= Category method; A= Attribute method; P= Price method

The P-method does not disentangle the pre- and post-harvest loss; the two loss types are thus reported jointly in the P-columns.

Chapter 4

On the origins of food loss

In this paper, we try to understand what the main causes of food losses (FL) are. Our results show that producers' education and experience and the number of years in which a producer has been involved in the production of a specific crop are significantly correlated with reduction in FL. Unfavorable climatic conditions, pest, and diseases, as well as, limited knowledge and access to equipment, credit, and markets are also challenges to increase production of higher quality and therefore reasons for FL. Policies to reduce and prevent food loss need to be targeted to specific commodities and contexts.

This chapter is based on:

Delgado, Luciana, Monica Schuster, and Maximo Torero. 2021. "On the Origins of Food Loss." Applied Economic Perspectives and Policy 43 (2): 750–80. https://doi.org/10.1002/aepp.13156.

4.1 Introduction

Why does so much food get lost along the food value chains? Little is known about what causes food loss in developing countries and how best to reduce them. It would be too simplistic to blame it on the carelessness of producers or vendors in the pre- or post-harvest handling of produce. Food loss can occur at different nodes of the value chain: production, harvest, or post-harvest stages, involving storage, transport, handling, or processing. Gaining insight into the causes of food loss (FL) can help develop the right interventions. Even though it would be impossible to completely eliminate food loss and waste, experts agree that there is room for reducing food loss and waste.

We implemented specially designed surveys to capture food loss along five staple food value chains in seven countries: potato in Peru and Ecuador, maize and beans in Honduras and Guatemala, maize in Mozambique, teff in Ethiopia, and wheat in China. Cereal grains, such as wheat, maize, potatoes, and beans, are the world's most popular food crops and form the basis of the staple diet in most developing countries. Our aim is to gain a better understanding of the links between food loss (FL) and a rich set of socio-economic features, agricultural production, and post-harvest treatment characteristics, as well as climatic conditions.

Methodologically, we use two alternative econometric models: the model of classical maximum likelihood estimation is used to assess the relationship between the right-hand side variables and the binary FL variable; fractional response models (GLM) are used on the share of product loss to account for the boundedness of the dependent variable. We use these models to estimate the relationship among these variables, using food loss data. Food loss is defined through the "attributes method" (see details in Delgado et al., 2021a). The results reveal specific areas that require investments to reduce food loss. They also show considerable heterogeneity of food loss. The causes of food loss appear to be highly specific to context and type of commodity.

This paper is organized as follows. The introduction is followed by a literature review, section 4.2, on the causes of food loss and waste in developing countries.

Section 4.3 presents the data and empirical approach. Section 4.4 presents descriptive statistics and key findings for Ethiopia, Ecuador, Honduras, Guatemala, Peru, China, and Mozambique. Section 4.5 discusses the findings with respect to the scientific literature. The paper ends with conclusions and policy recommendations.

4.2 Literature review on the causes of food loss

A review of the evidence suggests a wide range of possible causes, categorized into six groups: levels of human capital (education, experience); climatic conditions, insects or pest attacks; access to infrastructure and post-harvest infrastructure (especially storage facilities); access to technology, post-harvest crop management techniques and handling; economic incentives (standards); market access (mainly roads to markets). In practice, multiple factors are at play and reinforce one another. For instance, heat and humidity tend to damage perishable food products. It is more likely to be a problem in places where there is no temperature-controlled storage and transportation. The literature review is summarized in Table 4.1.

Kaminski and Christiaensen (2014), Maziku (2020), Doki et al. (2019), and Gebretsadik et al. (2019) find that human capital, or education and experience, to be negatively correlated with reduction of losses, that is higher the education, lower the level of FL.

Climatic conditions, such as high heat and humidity and post-harvest rainfall, have been found to be a major cause of post-harvest food loss in many contexts.[43] In African countries, there is high dependence on sun drying of crops among smallholder farmers. Post-harvest rainfall could lead to substantial losses, if crops are not dried properly before being stored or taken to the market.

[43] Ambler et al. (2018) and Tefera (2012), for instance, emphasize post-harvest rainfall as a main cause of food loss in Malawi and other Africa countries, while Kaminski and Christiaensen (2014), Basavaraja et al. (2007), Arah et al. (2016), and Kasso and Bekele (2016), identify high heat and moisture as main causes of food loss in sub-Saharan Africa and India.

Insects and pest attacks on produce have also been identified as important causes, typically compounded by heat or moist and poor storage conditions (Chegere, M., 2018). John (2014), for instance, finds that rodents are a major factor for post-harvest loss (PHL) of rice in Southeast Asia. Abdoulaye et al. (2016) report that more than 75 percent of farmers in Ghana, Tanzania, and Benin identified insects as the major cause for PHL, while most farmers in Ethiopia, Uganda, and Nigeria reported rodents and moisture as the main causes for PHL. Finally, Compton et al. (1997) and Baoua et al. (2014) show that each percentage point of insect infestation results in between 0.6 percent and 1 percent depreciation in the value of maize. Certain climatic conditions, especially heat and moisture, tend to increase the prevalence of insects, pests, and other bio-deterioration factors, especially when proper storage and transportation structures that control temperature and humidity are lacking.

Rosegrant et al. (2015) find that electricity, roads, and railways have an important role in PHL reduction. After getting the estimates of infrastructure on PHL reductions, the authors use the cost of infrastructure development to estimate a number of investment scenarios. These scenarios are later implemented in the IMPACT global food supply and demand model from the International Food Policy and Research Institute to simulate the impact of PHL reduction on food prices, security, consumer and producer surplus, net welfare gains, and benefit cost ratios to the investment. Overall, the authors find that reduction in PHL is not a low-cost alternative; rather it requires large investments and should be part of long-term investments to achieve food security. Kasso and Bekele (2016), Macheka et al. (2018), Kumar and Kalita (2017), Folayan (2013), Paneru et al. (2018), and Maziku (2020) also identify lack of storage as important factors behind the losses of horticultural crops, and lack of transportation facilities for losses of maize crops.

Table 4.1: Literature review on the origins of food loss

Author	Country/area	Commoditty	Cause	Effect on losses
Adewumi, M. O., Ayinde, O. E., Falana O. I. and Olatunji, G. B (2009)	Nigeria	Plantain/Banana	Distance between the farm and the market, cost of storage	positive
			Market experience, storage period, membership of cooperative	negative
Ahmed et al. (2015)	Pakistan	Kinnow Citrus	**Farm Level:** Orchard size in Acres	positive
			Farm Level: Experience (in years), Education (in Years), Picking method (dummy: use scissors vs manual picking), Picking Time (dummy: morning vs evening) **Wholesale Market Level:** loading method (dummy: stacking boxes vs open loading)	negative
Aidoo, R., Danfoku, R. A., & Mensah, J. O. (2014)	Ghana	Tomato	Gender (female), farm size, days of storage	positive
			Household size, membership of FBO, use of improved tomato variety	negative
Ambler et al. (2018)	Malawi	Maize	Post-harvest rainfall	positive
			Age of household, pre-harvest rainfall	negative
		Groundnuts	Household size, post-harvest rainfall	positive
			Age of household, pre-harvest rainfall	negative
		Soja	Household size, post-harvest rainfall	positive
			Age of household, pre-harvest rainfall	negative
Ansah, I.G.K., Tetteh, B.K.D. & Donkoh, S.A. (2017)	Ghana	Yam	Income, education,	positive
			Market participation, age, distance to the district capital	negative
Basavaraja, H. et al. (2007)	India	Rice	Total production crop, area under the crop, area under irrigation, area under commercial crops, weather (dummy)	positive
			Education	negative
		Wheat	Storage (dummy), weather (dummy)	positive
			Education	negative
Chegere, M. (2018)	SSA	Maize	***Pre-storage losses as a proportion of total harvest**: number of maize plots, area planted maize, ***Storage losses as a proportion of amount stored:** Drying period squared/100 (more than 26 days) **Marketing losses as a proportion of amount sold:** Number of transactions, Farmer transported maize to sale	positive
			***Pre-storage losses as a proportion of total harvest:** sunny wheather, harvest at maturity, Proper immediate handling after harvesting (spreading maize on a floor vs pilling it up or keeping it in sacks), sorted after harvesting, drying period (days), education, number of acting workers. ***Storage losses as a proportion of amount stored:** sunny wheather, harvest at maturity, Proper immediate handling after harvesting (spreading maize on a floor vs pilling it up or keeping it in sacks), sorted after harvesting, drying period (days), Storage facility desinfected, Used storage protectants (using chemical protectants and ashes for storage pests, and poisons and traps for rats), % sold 3 months after harvest, Area planted maize, education, Area planted maize, education **Marketing losses as a proportion of amount sold:** gender (male), number of acting workers, Area planted maize	negative
Doki N.O., Eya C.I., Tuughgba M.F., Akahi O.G., Ameh A., (2019)	Nigeria	Orange	Formal Education (education = 1, no education = 2), Handling (Adequate = 1, Not adequate = 2)	positive
			Method of harvesting (Hand picking = 1, Plucking with stick = 2)	negative
Folayan (2013)	Nigeria	Maize	Gender (male), source of information (extension service, Radio, TV, newspaper) and lack of modern storage facilities (type)	positive

Author	Country/area	Commoditty	Cause	Effect on losses
Gebretsadik, D., Haji, Jema., & Tegegne, B. (2019).	Ethiopia	Sesame	Land size, Distance of sesame farm from residence, total amount of sesame production, Weather condition (wind and rain is happening during harvesting to threshing time), Distance piles transported to threshing place, number of drying/stacking days, Mode of transportation (tractor/tracker vs caro/donkey),	positive
			Education level, Extension service contact	negative
Ismail, I et al. (2019)	Tanzania	Maize	Mode of transportation, storage time, quantity of maize transported, Methods for processing	positive
			Post harvest training, used of storage facility	negative
Khatun, M., & Rahman, M. (2019)	Bangladesh	Eggplants	Total harvested amount, Selling place (dummy: market level vs farm level)	positive
			Respondents Education, Packaging (dummy: improved vs traditional)	negative
Kikulwe, E.M.; Okurut, S.; Ajambo, S.; Nowakunda, K.; Stoian, D.; Naziri, D. (2018)	Uganda	Banana	**Producer:** gender (female), household size, variety (kibuzi), proportion of land allocated to banana production, monthly banana production, District * distance to market (Rakai district = 1), **Retail:** Availability information (vs. quality information)	positive
			Producer: distance to tarmac road, distance to market, district (Rakai), education level (secondary), District * distance to tarmac road (Rakai district = 1) **Retail:** gender (female), group member (vs no member), Buy from nearby markets (vs. buy from suppliers), Buy from producers directly (vs. buy from suppliers)	negative
Kuranen-Joko, D. N. & Dzahan Hilary Liambee (2017)	Nigeria	Tomato	Farm size (ha), labour type (family labour vs otherwise)	positive
			Farming experience,	negative
Macheka, L. et al. (2018)	Zimbawe	Tomato	Market price stability, harvest time (level of maturity required for costumers), determine processing volumes (any quantity vs specific quantity define by the market)	positive
			Storage facilities (cold rooms vs under the three/under plastics), storage practices (in pallets vs on the ground)	negative
Maziku (2020)	Tanzania	Maize	Quantity of production, bad weather condition, distance to the market, lack of modern storage facilities (type)	positive
			Education level, household size, market experience, and number of livestock	negative
Ngowi, E., Selejio, O. (2019)	Tanzania	Maize	Gender (male), age, harvest working days, use of hired labour, storage protectorants	positive
Paneru, R. et al. (2018)	Nepal	Maize	Early harvest, storage structure for shelled grain (jutte bag), Storage period for de-husked cobs	positive
			Altitude, ocupation of household head (farming), farmers experience, storage structure for husked cobs (vertical/horizontal frame/thakro), storage structure for de-husked cobs (bamboo basket/dokko)	negative
Rosegrant et al. (2015)			Electricity, roads, and railways	negative
Shee, A., Mayanja, S., Simba, E. *et al.* (2019)	Uganda	Maize	Total land size, de-husking technique (sticks, knifes vs bare hands), transport technique (truck vs bicycle), drying technique (plastic sheets vs tarpaulin), shelling techinque (sticks vs bare hands), place of sale (local market vs farmgate)	positive
			Gender (female), education level, training on PHL management, harvest technique (hand plucking vs machetes), storage facilities (storing in brick and mortar store room and use of sacks/containers vs storing maize in living room in the house), mill technique (manual milling vs commercial hammer mill)	negative
		White Fleshed sweetpotato	Age of hh, harvest technique (use of knife and spears vs hands), transport technique (in baskets transport by motorcycle vs in sacks carried by hand)	positive
			Gender (female),education level, training on PHL management, storage facilities (storing in a kitchen hut or in brick and mortar store rooms vs storing in living room in the house)	negative
		Orange Fleshed sweetpotato	Transport technique (by motorcycle vs in sacks carried by hand)	positive
			Education level, training on PHL management	negative

The risk of food loss is further escalated by poor post-harvest crop management techniques and handling. The techniques that constitute proper handling may vary from case to case. Tefera (2012) finds that improper post-harvest crop management and harvesting techniques account for between 14 percent and 36 percent of losses in maize grains in Africa. Insufficient drying, excessive drying, missing grains are some of the problems of the harvesting and drying stages. Other problems: improper threshing and shelling, which can cause grain breakage and grain cracking, are predominant in this stage; transportation to storage facilities; on-farm storage. Transportation to markets and marketing are identified as other critical areas where maize losses occur. Studies also point to credit constraints as a main bottleneck to technology adoption, preventing food loss reduction.[44]

Economic incentives affect PHL in a number of ways, although evidence is mixed. Goldsmith et al. (2015) demonstrate how poor market incentives lead producers of both soybeans and maize in tropical Brazil to accept significant post-harvest losses during the intercropping season. Farmers cannot afford any delay in harvesting soybeans, because they must ensure timely plantation of Maize, a high-value crop, on the same land. Any delay in planting would expose maize cultivation to higher risk of loss. Since the opportunity cost of delayed plantation of maize is higher, it may lead farmers to harvest and handle soybeans hastily. This is especially so, if the cost of hired seasonal farm labor is high relative to the market price. Therefore, this could lead to greater PHL for soybeans.

Rosegrant et al. (2015) find that better infrastructure facilitating transportation of products to markets reduces post-harvest losses, but that the impact will be stronger if farmers have better education, as it would enable them to adopt proper crop handling and processing techniques. The authors also find that post-harvest losses are correlated with farm size. Larger farms are more likely to incur post-harvest losses but experience fewer losses in the intensive margin. The

[44] HLPE, 2014. [This needs complete citation and should be added under references, rather than as a footnote.]

overall impact suggests a negative relationship between the share of post-harvest losses and farm size.

4.3 Data and methods

Data

We developed and implemented detailed surveys that allow us to quantify the extent of food loss at the producer level, using approaches that are comparable across commodities and regions. The survey enabled us to characterize the nature of food loss, specifically during the production and particular processing stages. The same surveys were conducted in seven countries (Ecuador, Peru, Honduras, Guatemala, Ethiopia, China, Mozambique) for five crops (potato, maize, beans, wheat, teff). We adapted our instrument for the specifications of each crop and country (for more extensive information on the survey, see Delgado et al., 2017, 2021a).

In all the countries, the surveyed sample was based on pre-census registration of producers who had produced the specific crop of interest in the last cropping season, which formed our baseline. The representative sample extracted from the baseline comprises 302 potato farmers in Honduras, and 411 potato farmers in Peru; 1,209 maize and beans farmers in Honduras, 1,155 maize and beans farmers in Guatemala, 1,203 teff farmers in Ethiopia, 1,114 wheat farmers in China, and 774 maize farmers in Mozambique.

The survey captures both quantitative losses and qualitative deterioration of the product, from pre-harvest to sale to an intermediary or end-user. While the survey instrument allows different ways to estimate food loss along the commodity value chains, in this paper we adhered to what has been defined the “attribute method” (see Delgado et al., 2021a). The method is based on the evaluation of a crop, according to inferior visual, tactile, and olfactory product characteristics. It leads to results that are comparable to alternative methods to estimate food loss, which have been used in other studies (Compton and Sherington, 1999; Delgado et al., 2021a).

Empirical approach

We use a statistical framework to assess the association between different socio-economic and production factors and food loss at the producer level. It is important to mention that our analysis does not provide evidence on causal impacts, as this would require our explanatory variables to be strictly uncorrelated with other characteristics that are either omitted from the regression framework or unobservable.

With this in mind, our main goal is to determine the correlation between producer FL and socio-economic characteristics, market access, agricultural production techniques, on-farm post-harvest practices and climatic and geographic variables (e.g., weather, pest, etc.). Given the uncertainties on the origins of loss, we believe that the intensity of correlations can provide insight into the causal effectiveness of targeted interventions for future studies.

For each commodity and country, we estimate regressions of the following type:

$$FL_{i,c,x} = \beta_0 + \beta_1 X_{i,c,x} + \beta_2 Z_{i,c,x} + \beta_3 N_{i,c,x} + \beta_4 W_{i,c,x} + \pi_v + \rho_{AE} + \varepsilon_{i,c,x}$$

where FLi,c,x is an indicator of FL of producer © in country c and for commodity x. FL is either a discrete outcome (0 if no loss; 1 if at least some loss) or the share of the lost production, as estimated with the "attribute method," and including both quantity and quality degradation. Xi,c,x are a set of socio-economic characteristics, Zi,c,x agricultural production characteristics, and Ni,c,x are post-harvest managing and handling techniques, including storage. Wi,c,x is a proxy for production issues highlighted by the producer during growing process or post-harvest stages (e.g., unfavorable climatic conditions, limited knowledge or information). While the first three sets of variables intend to capture characteristics, knowledge and instruments available at the farm level, Wi,c,x captures external, growing conditions and limitations. Finally, location-fixed effects πv are included to control for common district, municipality or village effects, and ρ_{AE} are the agro-ecological zone dummies, which control for climatic conditions that could be correlated with farm loss. $\varepsilon_{l,c,x}$ is the unobservable error term.

We use classical maximum likelihood estimation to assess the parameters β. Probit regressions are used to estimate the relationship between the right-hand side variables and the binary FL variable. Fractional response models (GLM) are used on the share of product loss to account for the boundedness of the dependent variable (Papke and Wooldridge, 1996, 2008).45 We calculate estimated marginal effects for both models. Because estimation errors between different countries and commodities in the same geographical areas are correlated with the same idiosyncratic shocks, we cluster the standard errors at the geographic level disaggregation in each survey.

4.4 Results

Producer characteristics

Table 4.2 shows summary statistics of the producers across the different countries and commodity groups. Around 90 percent of all sampled producers are male in all the countries and across value chains. On average, they are 47 years old and have between 17 and 30 years of experience in growing the analyzed crops. Most producers have primary education. In Peru and China, almost half of the producers also completed secondary education. Producers are rural smallholders. They cultivate between 0.35 ha of land (beans in Guatemala) and 3.5 ha of land (potato in Ecuador). On average, they live 2.5 hours away from the closest village market.

[45] Due to the left-censored nature of the dependent variable, Tobit models have also been tested (Wooldridge, 2002). Tobit and GLM results are very similar.

Table 4.2: Producer characteristics, across value chains and countries

Variable name			Ecuador: potato (N = 302)		Peru: potato (N = 411)		Guatemala: beans (N = 450)		Honduras: beans (N = 685)		Guatemala: maize (N = 922)		Honduras: maize (N = 1024)		Mozambique: maize (N = 774)		Ethiopia: teff (N = 1203)		China: wheat (N = 1114)	
			mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
Socio-economic characteristics	Gender (male)		93%	0.26	80%	0.40	88%	0.33	95%	0.22	87%	0.33	95%	0.22	63%	0.48	94%	0.23	84%	0.37
	Age (years)		50.15	13.97	44.36	14.02	48.75	15.03	47.78	14.47	50.23	15.01	48.52	15.07	43.88	14.47	44.21	11.43	53.85	10.90
	Education	no education	2%	0.14	4%	0.19	29%	0.45	17%	0.38	31%	0.46	19%	0.39	12%	0.32	37%	0.48	6%	0.24
		primary	74%	0.44	37%	0.48	65%	0.48	79%	0.40	59%	0.49	78%	0.42	72%	0.45	39%	0.49	25%	0.43
		secondary	12%	0.32	48%	0.50	4%	0.19	2%	0.16	4%	0.20	2%	0.15	16%	0.37	20%	0.40	49%	0.50
		>secondary	12%	0.33	11%	0.31	2%	0.14	1%	0.09	6%	0.24	1%	0.09	0%	0.00	0%	0.05	20%	0.40
	Household size		4.00	1.61	3.70	1.46	6.11	2.62	5.03	2.12	5.84	2.77	5.08	2.38	6.63	3.43	6.11	2.12	4.77	2.10
	Main income from agriculture		57%	0.50	94%	0.23	na		na		na		na				na		na	
	Experience in cultivating crop		24.06	13.80	16.95	12.87	22.53	15.17	26.37	15.16	25.29	16.23	27.03	16.21	20.70	13.28	22.09	10.99	29.99	12.46
Market access	Cost to reach market (USD/ Kg)		2.49	2.79	0.05	0.04	1.38	1.11	0.02	0.03	1.00	0.91	0.02	0.03	na		na		na	
	Time to reach market (hours)		0.81	0.31	0.96	0.61	1.38	1.11	3.28	3.34	1.00	0.90	3.59	3.78	2.62	1.75	4.05	2.88	5.25	1.78
Production	Quantity produced last harvest		49,099	105,760	70,310	301,281	145	256	629	1,171	1,023	1,781	2,251	14,406	2,094	3,807	1,479	1,404	9,260	39,369
	Area cultivated (in hectares)		3.48	5.91	2.82	7.78	0.35	0.76	1.09	1.47	0.52	1.10	1.45	3.14	1.93	1.93	1.23	1.13	1.47	6.45
	Improved seeds (dummy)		16%	0.36	44%	0.50	4%	0.19	9%	0.29	18%	0.38	19%	0.40	32%	0.46	74%	0.44	79%	0.41
	Resistant variety (dummy)		29%	0.46	49%	0.50	na				na				30%	0.46	13%	0.34	na	
	Time of planting: primera vs postrera		*na*		*na*		75%	0.43	33%	0.47	96%	0.20	69%	0.46			*na*		*na*	
	Number of different inputs applied[a]		3.03	0.30	3.06	0.25	1.72	1.05	2.72	1.20	2.03	1.06	2.94	0.91	0.15	0.47	2.82	0.86	4.14	0.96
	Number of different field maintenance activities[b]		0.77	0.77	1.31	0.74	0.04	0.20	0.10	0.30	0.06	0.24	0.10	0.31			na			
	Number of mechanic production activities[c]		0.79	0.53	1.25	1.15	0.05	0.39	0.32	0.78	0.20	0.75	0.41	1.06	0.14	0.61	0.06	0.24	1.82	0.83
	Harvest technique	'azadon'			91%	0.28														
		tractor or combine			5%	0.23													92%	0.27
		'lampa'			3%	0.18														
	Hired labor (dummy)		94%	0.23	88%	0.32	37%	0.48	94%	0.24	70%	0.46	95%	0.22	47%	0.50	57%	0.50	18%	0.38
Post-harvest[f]	Nb of post-harvest activities[d]		2.36	0.78	1.56	1.39	3.88	0.66	3.69	0.83	3.60	0.90	3.58	0.92	5	1.29	8.84	0.40	2.79	1.21
	Mechanical drying and		*na*				2%	0.13	4%	0.19	5%	0.22	5%	0.22	na		na			
	Mechanical threshing activity						*na*		6%	0.24	*na*		17%	0.37						
	Mechanical transport		25%	0.44	54%	0.50	16%	0.36	23%	0.42	28%	0.45	25%	0.43	0.4%	0.06	0%		49%	0.50
	Storage (dummy)		7%	0.25	27%	0.44	99%	0.10	89%	0.31	99%	0.12	92%	0.28	89%	0.31	99%	0.12	47%	0.50
	Storage time (in days)		15	16	26	42	187	105	146	85	215	91	151	76	50	66.38	126	66	46	70
	Storage location	Silo	0%		0%		3%	0.17	10%	0.30	2%	0.14	53%	0.50	0.15%	0.04	0%	0.05	1%	0.11
		Granary/ Barn	30%	0.47	41%	0.49	1%	0.12	4%	0.20	9%	0.29	5%	0.21	7%	0.25	21%	0.41	8%	0.28
		House (bag)	70%	0.47	59%	0.49	96%	0.21	85%	0.35	89%	0.32	43%	0.49	39%	0.49	61%	0.49	30%	0.46
		House (bulk)	*na*														*na*		61%	0.49
		Traditional Pit													54%	0.50	6%	0.23	*na*	
		Traditional Dibignet															11%	0.32		
		Open air															*na*		8.35%	0.28
	Number of storage conservation activities[e]		0.55	0.60	0.77	0.70	0.41	0.57	0.68	0.47	0.47	0.51	0.78	0.43	1.51	0.60	1.64	0.70	0.17	0.38
Sales	Percentage sold (versus own consumption, barter, animals or seeds)		81%	0.16	84%	0.16	31%	0.25	40%	0.32	21%	0.22	26%	0.27	29%	0.23	36%	0.25	86%	0.20
	Sale location[g]	house or plot	75%	0.44	46%	0.50	63%	0.48	86%	0.35	72%	0.45	89%	0.32	50%	0.50	4%	0.19	45%	0.50
		nearest town	9%	0.29	28%	0.45	26%	0.44	2%	0.14	23%	0.42	2%	0.14	13%	0.34	51%	0.50	8%	0.27
		village market	17%	0.37	34%	0.47	6%	0.24	12%	0.33	7%	0.25	8%	0.27	46%	0.50	48%	0.50	40%	0.49
	Type of buyer the farmers sells	middlemen	69%	0.46	62%	0.49	5%	0.22	55%	0.50	6%	0.24	29%	0.45	69%	0.46	61%	0.49	90%	0.30
		wholesaler	31%	0.46	45%	0.50	21%	0.41	17%	0.38	15%	0.35	12%	0.32			19%	0.39	0%	
		processor	1%	0.10	1%	0.12	1%	0.09	0%		3%	0.18	3%	0.17	7%	0.25	1%	0.09	7%	0.26
		consumer	1%	0.11	8%	0.27	67%	0.47	31%	0.46	76%	0.43	59%	0.49	23%	0.42	21%	0.41	1%	0.12
	Number of transactions to sell		1.53	1.94	3.02	4.34	1.97	3.30	1.26	1.28	2.03	6.56	1.39	3.49	1.32	0.70	2.15	1.63	5.82	41.30

Note: a) This includes fertilizers, insecticides, herbicides, and fungicides; b) This includes activities such as irrigation, trimming, and pruning; c) Machine-driven activities, such as soil preparation, sowing, pest control, fertilizer application, weeding, mulching, cutting, and harvest; d) This includes activities such as selection, classification, drying, etc.; e) This includes activities such as chemical fumigation, natural fumigation, and ventilation; f) storage summary statistics are obtained from the restricted sample of farmers storing grains; g) These variables are not mutually exclusive, as farmers can have more than one sales location and type of buyer.

Mechanization and technology adoption in production and post-harvest activities is low on average, but considerable variation exists across countries and crops. Around two thirds of all farmers use improved seeds for teff in Ethiopia and for wheat in China. However, less than 20 percent use improved seeds to grow beans and maize in Guatemala and Honduras. Resistant crop varieties are not widely common in Peru, Ecuador, and Mozambique. Machine-driven production methods, such as soil preparation, sowing, pest control, fertilizer application, weeding, mulching, cutting and harvesting, are most widely used in the Chinese wheat value chain and Peruvian potato value chain. However, they are almost nonexistent in the bean value chain in Guatemala, the maize value chain in Mozambique, and the teff value chain in Ethiopia. Mechanization in post-harvest activities is even less common. Only in Honduras do farmers engage in mechanical threshing of beans and maize; very few farmers in Honduras and Guatemala mechanically dry and winnow the beans and maize. On average, producers use 2.5 different types of inputs to grow their crops (fertilizers, insecticides, herbicides, and fungicides), but there is a large variation between countries, ranging from almost no input (maize in Mozambique) to more than four different types of inputs (wheat in China).

In six out of the nine value chains, almost all producers store their grain as food reserves and seed for the next season for an average of five months (beans and maize value chains in Guatemala and Honduras; teff value chain in Ethiopia). About 50 percent of all wheat farmers in China and 30 percent of all potato farmers in Peru store their produce for an average of one month. Only farmers in Ecuador rarely store the potatoes they grow. Around 63 percent of all farmers store their produce in their house in bulk or in bags. Around 14 percent of all farmers store them in traditional storage facilities. Less than 10 percent of farmers use metal or plastic silos, with the exception of maize farmers in Honduras.

Finally, across all countries and commodities, on average of about 50 percent of the crops are sold by farmers. The share is around 80 percent for the potato value chains in Ecuador and Peru, and for wheat in China. The share is considerably lower at around 30 percent in Guatemala, Honduras, Ethiopia, and Mozambique. The product is sold directly to an intermediary on farmers' plot.

Likelihood and magnitude of food loss

Table 4.3 provides insight into the likelihood of food loss and the magnitude of losses across the different value chains and countries. As mentioned above, loss figures are estimated with the "attributes approach" described in Delgado et al. (2021a). The methods foresee that the producer evaluates its produce based on a specific number of quality attributes and defines the share of total production affected by the inferior damage attribute. The product attributes are identified and validated prior to the survey implementation in collaboration with commodity experts and local value chain actors.[46] The quantity and quality degradation at the farm level are thus defined by the sum of the total produce loss (equal to the total amount that completely disappeared from the value chain between harvest and sale or consumption) and the share of product affected by a damage attribute (meaning not totally lost and can still be used, but the quality is degraded). This degradation can be expressed either in weight or in economic value (Table 4.3).

Table 4.3 shows that most farmers suffered at least some weight or value losses in the previous harvest season. The figure ranges from 64 percent of all teff farmers in Ethiopia to 95 percent of all wheat farmers in China and 97 percent of all maize farmers in Guatemala. On average, 20 percent of the farmers' produce was lost. Figures range from 14 percent of all product lost in the potato value chain in Ecuador to 31 percent loss in the teff value chain in Ethiopia. Percentage losses expressed in value tend to be 4 percent smaller on average than those expressed in weight, indicating that some quality degradations at the farm level do not seem to be penalized by the market.

[46] The number of product attributes varies between 10 and 14 based on the commodity and country.

Table 4.3: Total quantity and quality degradation at producer level (expressed in weight and value of total production)

	Number of observations	% of farmers with weight or value loss	Share of product lost, in weight* (if loss >0)	Share of product lost, in value (if loss >0)
Ecuador - Potato	287	87%	14%	12%
Peru - Potato	355	94%	21%	17%
Guatemala - Beans	431	87%	23%	21%
Honduras - Beans	650	74%	27%	24%
Guatemala - Maize	884	97%	21%	14%
Honduras - Maize	988	91%	18%	17%
Mozambique - Maize	765	85%	16%	13%
Ethiopia - Teff	1,186	64%	31%	14%
China - Wheat	1,099	95%	12%	13%

Note: Estimation of the loss through the "Attribute method" (see Delgado et al., 2021a)
Share of product lost, in weight = Quantity of product that disappeared from value chain + Quantity of product affected by a damage attribute. Share of product lost, in value = Economic value of the product lost

Regression results

Tables 4.4-4.8 presents Probit and GLM regression results respectively on the probability of incurring a loss and on the share of produce lost. We classified the potential origins of food loss in five groups: socio-economic characteristics of the farmer; market access; mechanization and technology; storage facilities; and growing conditions (pests and disease); and climatic conditions. Overall, we notice that there is a considerable heterogeneity in the determinants of food loss across commodity and country contexts. It is important to highlight that the models do not provide evidence on causal impacts; yet, they can be helpful for future hypothesis tests for causality.

Socio-economic characteristic.

Most farmers are men, but there is no clear gender pattern in food loss across countries and commodities. For example, being a male farmer tends to be correlated with 4.9 to 10.9 less percentage points share of beans loss, but it is associated with respectively, about 10 percentage points more likelihood to incur in a loss of maize and 5 more percentage points share of maize loss in Guatemala and Honduras. No correlation with gender is detected in other commodities value chains. Age, education, and experience tend to be negatively correlated with the probability and share of food losses. In particular, being older is associated with an about 3 percentage points less likelihood to incur in a loss in the maize value chain in Guatemala and Honduras. Formal education, like primary, secondary, or higher education, significantly correlates with 5 to 30 percentage points reduction in losses in the potato value chain in Ecuador and Peru, the bean value chain in Honduras, and the wheat value chain in China. The number of years in which a producer has been producing a specific crop significantly correlates with the reduction in losses in the potato value chain in Ecuador, the bean and maize value chain in Guatemala, and the maize value chain in Mozambique. We have the farmers' income data only for Peru and Ecuador. In addition, we find that in Peru and Ecuador when a producer's main income stems from an agricultural activity, it is correlated with lower losses that is statistically significant (all else equal, a producer's main income that stems from an agricultural activity is associated with 47 percentage points less likelihood of any loss in Peru and with respectively 14 and 68 percentage points less share of food loss in Ecuador and Peru). This result is in line with the outcome we find on crop cultivation experience.

Market access

The costs or time to reach markets have a significant correlation with increased losses in five of the seven countries. In Peru, Guatemala, Mozambique, Ethiopia, and China, the absence of markets can represent important limitations for farmers. Farmers in these countries decide not to market (or even harvest) all produce because of their high costs relative to the market price (an increase of the cost of a KG of produce to reach a market or the time – in 10 hours – to reach a market, can increase share of produce loss by an average of 0.4 percentage points). Mechanical transport with a car is associated with a significant increase of these costs through additional losses during travel in beans and maize value chains in Guatemala. The farmers in our survey mention lack of access to markets and credits as a challenge to increasing production of high-quality products.

Table 4.4: Regression results of the probability of experiencing a loss and the total share lost; potato value chain in Ecuador and Peru

		Ecuador		Peru	
		Probit	GLM	Probit	GLM
Socio-economic variables	Male producer	-0.034	0.006	-0.021	0.021
		(0.123)	(0.031)	(0.026)	(0.026)
	Age of producer (in 10 years)	0.011	0.020*	-0.005	-0.003
		(0.030)	(0.012)	(0.029)	(0.025)
	Education: Primary (vs no Education)	-0.937***	-0.106**	-0.011	-0.050*
		(0.208)	(0.041)	(0.007)	(0.028)
	Education: Secondary or higher (vs no Edu)	-0.994***	-0.061*	-0.038	-0.054
		(0.200)	(0.036)	(0.038)	(0.051)
	Experience in cultivation of potato (in 10 years)	-0.016	-0.011***	-0.004	-0.009
		(0.041)	(0.002)	(0.026)	(0.031)
	Main income from agriculture (vs non-agric)	0.029	-0.014***	-0.047***	-0.068*
		(0.044)	(0.004)	(0.007)	(0.035)
Market	Cost to reach market (USD/ Kg)	0.004	-0.006	1.187***	1.096*
		(0.011)	(0.005)	(0.127)	(0.577)
Production	log(Total production potato)	-0.008		-0.019	
		(0.010)		(0.015)	
	Resistant potato variety	0.058	-0.035***	-0.085***	0.002
		(0.066)	(0.012)	(0.018)	(0.034)
	Number of different inputs applied[a]	-0.054	-0.003	-0.041	-0.025
		(0.065)	(0.025)	(0.027)	(0.088)
	Number of different field maintenance activities[b]	-0.024*	-0.011**	0.009	0.000
		(0.014)	(0.004)	(0.020)	(0.017)
	Number of production activities done mechanically[c]	0.160***	0.013	-0.021	-0.030***
		(0.052)	(0.035)	(0.013)	(0.007)
	Harvest technique: tractor vs azadon			0	-0.296***
				.	(0.070)
	Harvest technique: lampa vs azadon			0	-0.256***
				.	(0.048)
	Hired labor for harvest	0.063	-0.079***	-0.006	-0.017
		(0.121)	(0.011)	(0.088)	(0.047)
Post-harvest	Storage dummy	0.081	-0.026	0.002	0.004
		(0.157)	(0.047)	(0.010)	(0.045)
	Nb of post-harvest activities[d]	-0.116***	0.013	0.055***	-0.013
		(0.019)	(0.014)	(0.006)	(0.011)
	Mechanical transport	-0.001	0.021***	0.049	0.026
		(0.073)	(0.007)	(0.056)	(0.027)
Production problems & limitations to produce high quality (as perceived by the producer)	Climate	0.072	0.030**	0.028	0.024
		(0.056)	(0.015)	(0.051)	(0.033)
	Pests	0.009	-0.001	0.035***	0.060*
		(0.025)	(0.014)	(0.001)	(0.033)
	Limited knowledge	-0.082*	0.037**	-0.034	-0.01
		(0.047)	(0.015)	(0.060)	(0.015)
	Limited equipment	-0.036	-0.015	0.044***	0.113***
		(0.033)	(0.009)	(0.011)	(0.043)
	Limited credit access	0.138**	-0.015	-0.047	0.056**
		(0.070)	(0.015)	(0.027)	(0.026)
Location fixed effects		parroquia	parroquia	district	district
Agroecological zone		yes	yes	yes	yes
No. of Obs.		229	287	290	369

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parenthesis clustered at the canton level for Ecuador and at the province level for Peru. a) This includes fertilizers, insecticides, herbicides and fungicides; b) This includes irrigation, "aporque" and "corte del yuyo"; c) Machine-driven activities include soil preparation, sowing, pest control, fertilizer application, weeding, "aporque," "corte del yuyo," harvest; d) This refers to selection, classification, drying, and "acarreo" after drying

Table 4.5: Regression results of the probability of experiencing a loss and the total share lost; bean value chain in Guatemala and Honduras

		Guatemala				Honduras			
		Probit		GLM		Probit		GLM	
Socio-economic variables	Male producer	-0.054	-0.052	-0.049**	-0.057***	-0.078	-0.120	-0.075*	-0.109**
		(0.054)	(0.040)	(0.020)	(0.019)	(0.089)	(0.131)	(0.042)	(0.048)
	Age of producer (in 10 years)	-0.001	0.000	0.001	0.001	0.001	-0.001	-0.001	-0.003
		(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.002)	(0.002)
	Education: Primary (vs no education)	-0.027	-0.047	0.011	0.006	-0.033	-0.041	-0.023	-0.035
		(0.065)	(0.068)	(0.032)	(0.034)	(0.055)	(0.054)	(0.036)	(0.024)
	Education: Secondary or higher (vs no education)	0.178	0.191	0.030	0.034	-0.260***	-0.229***	-0.105**	-0.171**
		(0.108)	(0.126)	(0.054)	(0.064)	(0.064)	(0.065)	(0.053)	(0.068)
	Experience in cultivation of beans (in 10 years)	-0.025	-0.037***	-0.005	-0.002	-0.003	0.007	0.011	0.017
		(0.016)	(0.011)	(0.007)	(0.008)	(0.023)	(0.023)	(0.009)	(0.012)
Market	Cost to reach market (USD/ Kg)	-0.011	-0.005	0.022*	0.026**	-3.048	-1.350	-1.81	-1.132
		(0.040)	(0.038)	(0.012)	(0.012)	(2.011)	(2.804)	(1.400)	(1.577)
Production	Time of planting: primera vs postrera	0.015	-0.008	0.040	0.031	0.012	-0.023	-0.010	-0.044***
		(0.077)	(0.072)	(0.032)	(0.030)	(0.033)	(0.039)	(0.030)	(0.014)
	log(Total production beans)	0.044***	0.044***			0.012	-0.004		
		(0.011)	(0.013)			(0.021)	(0.018)		
	Improved seeds (dummy)	-0.126	-0.110	-0.063	-0.069	0.118	0.101	-0.065***	-0.027
		(0.112)	(0.122)	(0.049)	(0.056)	(0.089)	(0.080)	(0.022)	(0.023)
	Number of different inputs applied[a]	0.032	0.036*	0.007	0.010	0.008	0.004	-0.002	0.007
		(0.021)	(0.020)	(0.009)	(0.009)	(0.021)	(0.016)	(0.006)	(0.006)
	Number of different field maintenance activities[b]	-0.072	-0.010	0.005	0.023	0.075	0.119*	0.049	0.018
		(0.194)	(0.151)	(0.018)	(0.043)	(0.068)	(0.067)	(0.038)	(0.058)
	Number of production activities done mechanically[c]	0.000	0.000	-0.012	-0.003	-0.071**	-0.088***	0.004	0.004
		.	.	(0.010)	(0.013)	(0.033)	(0.028)	(0.020)	(0.019)
	Hired labor for harvest	-0.045**	-0.038*	0	0.006	-0.173*	-0.192***	-0.038	-0.002
		0.02	0.021	0.01	0.01	0.089	0.051	0.054	0.046
Post-harvest	Storage dummy	0	0.000	0.128***	0.000	0.199***	0.000	0.072***	0.000
		.	.	(0.045)	.	(0.045)	.	(0.027)	.
	Nb of post-harvest activities[d]	-0.026	-0.027	-0.027**	-0.029**	0.032	0.043*	0.020	0.030
		(0.025)	(0.025)	(0.012)	(0.013)	(0.025)	(0.023)	(0.020)	(0.019)
	Mechanical drying and winnowing	0.047	0.028	-0.207***	-0.239***	0.101*	0.080	0.007	-0.019
		(0.260)	(0.272)	(0.078)	(0.080)	(0.053)	(0.051)	(0.050)	(0.026)
	Mechanical threshing activity					0.102**	0.130**	0.110***	0.104***
						(0.043)	(0.064)	(0.030)	(0.034)
	Mechanical transport	0.102**	0.113**	0.055*	0.067**	-0.069	-0.068	-0.006	-0.006
		(0.049)	(0.055)	(0.029)	(0.029)	(0.074)	(0.066)	(0.031)	(0.033)
Storage	Storage time (in months)		0.001		-0.003		0.007		0.011***
			(0.005)		(0.003)		(0.008)		(0.004)
	Storage: Modern vs Traditional storage		-0.183**		-0.162***		0.021		-0.018
			(0.076)		(0.052)		(0.044)		(0.023)
	Number of storage conservation activities[e]		-0.026		0.012		-0.01		-0.040*
			(0.030)		(0.012)		(0.057)		(0.022)
Production problems & limitations to produce high quality (as perceived by the producer)	Climate	0.097***		0.033		0.079***		0.061***	
		(0.028)		(0.024)		(0.024)		(0.020)	
	Animals/ rodents	0.129		0.051***		0.277***		-0.007	
		(0.101)		(0.016)		(0.056)		(0.023)	
	Pests	0.041		0.028		-0.026		0.034	
		(0.035)		(0.023)		(0.020)		(0.023)	
	Diseases	-0.012		0.055**		0.022		0.027	
		(0.040)		(0.022)		(0.017)		(0.018)	
	Limited market access	-0.022		0.015		0.140***		0.123***	
		(0.049)		(0.028)		(0.027)		(0.042)	
Location fixed effects		municipality	municipality	municipality	municipality	municipality	municipality	municipality	municipality
Agroecological zone dummies		yes	yes	yes	yes	yes	yes	yes	yes
No. of Obs.		324	324	431	426	636	568	644	574

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parenthesis clustered at the department level for Honduras and Guatemala. a) This includes fertilizers, insecticides, herbicides and fungicides; b) This includes irrigation and "chapeo"; c) Machine-driven production activities include cleaning, sowing, herbicide application, pest control, fertilizer application, and harvest; d) This refers to winnowing (sopla), threshing (desgrane), drying, putting in bags, and transport; e) This includes chemical fumigation, natural fumigation, and ventilation. The second column of each model reports results conditional on storage.

Table 4.6: Regression results of the probability of experiencing a loss and the total share lost; maize value chain in Guatemala, Honduras and Mozambique

		Guatemala				Honduras				Mozambique			
		Probit		GLM		Probit		GLM		Probit		GLM	
	Male producer	0.095***	0.101**	0.052**	0.052**	0.085***	0.065	-0.010	-0.020	-0.022*	-0.011	-0.005	0.003
		(0.036)	(0.049)	(0.025)	(0.023)	(0.022)	(0.040)	(0.025)	(0.033)	(-0.012)	(-0.009)	(-0.012)	(-0.011)
	Age of producer (in 10 years)	-0.003**	-0.004***	0.001	0.000	-0.002**	-0.003***	-0.001*	-0.001	0.001***	0.000	0.001***	0.000
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Socio-economic variables	Education: Primary (vs no education)	-0.141**	-0.123	-0.024	-0.033	0.016	0.005	0.006	0.004	-0.023	-0.032	-0.005	-0.003
		(0.070)	(0.092)	(0.028)	(0.030)	(0.010)	(0.013)	(0.018)	(0.019)	(-0.036)	-(0.033)	-(0.035)	-(0.012)
	Education: Secondary or higher (vs no education)	0.000	0.000	-0.003	-0.018	-0.014	0.010	-0.002	0.008	-0.021	-0.029	-0.002	-0.019***
		.	.	(0.029)	(0.040)	(0.019)	(0.063)	(0.058)	(0.059)	-(0.048)	-(0.032)	-(0.040)	-(0.001)
	Experience in cultivation of maize (in 10 years)	0.001	0.017	-0.012**	-0.005	0.019	0.025	0.009	0.009	-0.024***	-0.007***	-0.022	0.002
		(0.016)	(0.012)	(0.005)	(0.005)	(0.020)	(0.021)	(0.010)	(0.010)	-(0.009)	(0.000)	-(0.014)	-(0.007)
Market	Cost to reach market (USD/ Kg)	-0.043	-0.004	0.037***	0.033***	-1.406	-0.183	-0.101	0.027				
		(0.027)	(0.046)	(0.012)	(0.012)	(0.993)	(1.025)	(0.759)	(0.705)				
	Time to reach market (in 10 hours)									-0.023	-0.013	-0.028	0.023***
										-(0.034)	-(0.021)	-(0.035)	-(0.004)
	Time of planting: primera vs postrera	0.000	0.000	-0.064	-0.047	0.007	-0.024	0.029*	0.024				
		.	.	(0.047)	(0.048)	(0.023)	(0.029)	(0.017)	(0.019)				
	log(Total production maize)	0.004	-0.057**			0.028***	0.027***			0.065***	0.067***		
		(0.029)	(0.023)			(0.009)	(0.009)			-(0.013)	-(0.011)		
	Improved seeds (dummy)	-0.055**	-0.061	-0.015	-0.007	-0.033	-0.044*	-0.033*	-0.031*	-0.032	-0.023	-0.027	-0.022
		(0.024)	(0.041)	(0.015)	(0.011)	(0.023)	(0.025)	(0.020)	(0.018)	-(0.020)	-(0.015)	-(0.024)	-(0.053)
	Resistant variety									-0.032	-0.042	-0.024	0.013
										-(0.025)	-(0.034)	-(0.023)	-(0.014)
Production	Number of different inputs applied[a]	0.000	0.020	-0.013*	-0.006	0.012	0.019***	-0.004	0.009	-0.007	-0.017	0.001	-0.007***
		(0.023)	(0.028)	(0.007)	(0.010)	(0.008)	(0.006)	(0.010)	(0.011)	-(0.020)	-(0.019)	-(0.017)	-(0.002)
	Number of different field maintenance activities[b]	0.000	0.000	0.010	0.004	-0.019	-0.022	-0.007	0.001				
		.	.	(0.049)	(0.029)	(0.029)	(0.029)	(0.022)	(0.023)				
	Number of production activities done mechanically[c]	0.073**	-0.047	0.034***	0.032***	-0.010	-0.022	0.012	0.006	-0.044***	-0.045***	-0.040*	-0.004
		(0.030)	(0.046)	(0.009)	(0.012)	(0.010)	(0.015)	(0.008)	(0.015)	-(0.014)	-(0.013)	-(0.021)	-(0.011)
	Hired labor for harvest	0.004	0.066	0.007	0.006	0.009	0.035	0.022	0.050*	-0.003***	-0.003	0.041**	-0.003
		(0.036)	(0.042)	(0.012)	(0.012)	(0.040)	(0.042)	(0.035)	(0.027)	(0.000)	-(0.004)	-(0.019)	-(0.027)
	Storage dummy	0.000	0.000	-0.031	0.000	0.068**	0.000	0.057***	0.000	0.137***	0.000	0.124***	0.000
		.	.	(0.038)	.	(0.031)	.	(0.020)	.	-(0.019)	.	-(0.013)	.
	Nb of post-harvest activities[d]	-0.068***	-0.066***	0.015*	0.018**	0.002	-0.003	0.001	0.003	0.024***	0.018	0.032***	
		(0.022)	(0.018)	(0.009)	(0.008)	(0.009)	(0.012)	(0.009)	(0.009)	-(0.005)	-(0.019)	-(0.009)	
Post-harvest	Mechanical drying and winnowing	0.140	0.033	0.018	-0.007	-0.058	-0.110***	-0.024	-0.022				
		(0.107)	(0.118)	(0.014)	(0.011)	(0.049)	(0.025)	(0.026)	(0.036)				
	Mechanical threshing activity	0.161***	0.182***	-0.042	-0.043	-0.017	0.003	-0.024	-0.009				
		(0.047)	(0.055)	(0.048)	(0.042)	(0.031)	(0.028)	(0.031)	(0.031)				
	Mechanical transport	0.159***	0.041	0.058***	0.053***	-0.073***	-0.090***	-0.01	-0.018				
		(0.037)	(0.042)	(0.015)	(0.015)	(0.016)	(0.024)	(0.019)	(0.020)				
	Storage time (in months)		0.006		-0.004		0.003		-0.002		-0.012		-0.003
			(0.006)		(0.003)		(0.004)		(0.002)		-(0.008)		-(0.004)
Storage	Storage: Modern vs Traditional storage		-0.306***		-0.137		-0.012		-0.022*		-0.058		-0.010
			(0.101)		(0.110)		(0.021)		(0.013)		-(0.040)		-(0.048)
	Number of storage conservation activities[e]		0.068*		0.003		-0.04		-0.031**		0.010		0.044**
			(0.036)		(0.011)		(0.031)		(0.014)		-(0.087)		-(0.019)
	Climate	0.175***		0.072***		0.087***		0.008		0.048	0.009	0.042	0.031***
		(0.040)		(0.019)		(0.031)		(0.021)		-(0.031)	-(0.008)	-(0.037)	-(0.009)
	Animals/ rodents	0.125*		-0.009		0.051		0.035**					
		(0.065)		(0.015)		(0.042)		(0.016)					
Production problems & limitations to produce high quality (as perceived by the producer)	Pest	-0.006		0.007		0.011		0.040***		0.029	0.054***	0.027	0.013
		(0.039)		(0.015)		(0.021)		(0.011)		-(0.026)	-(0.006)	-(0.037)	-(0.009)
	Knowledge									-0.023	-0.018	-0.041	0.010
										-(0.031)	-(0.039)	-(0.038)	-(0.014)
	Disease	0.035		0.057***		-0.045		0.033**					
		(0.077)		(0.016)		(0.028)		(0.014)					
	Soil quality									0.068***	0.072***	0.060***	0.010***
										-(0.012)	-(0.007)	-(0.004)	-(0.001)
	Limited market access	-0.134***		0.010		0.045*		0.015		0.046	0.011	0.064**	0.027*
		(0.051)		(0.025)		(0.026)		(0.025)		-(0.030)	-(0.036)	-(0.031)	-(0.016)
Location fixed effects		municipality	municipality	municipality	municipality	municipality	municipality	municipality	municipality	district	district	district	district
Agroecological zone dummies		yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
No. of Obs.		245	244	876	852	823	727	972	891	741	626	741	664

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parenthesis clustered at the department level for Honduras and Guatemala. a) This includes fertilizers, insecticides, herbicides and fungicides; b) This includes irrigation and "chapeo"; c) Machine-driven production activities include cleaning, sowing, herbicide application, pest control, fertilizer application, and harvest; d) This refers to winnowing (sopla), threshing (desgrane), drying, putting in bags, and transport; e) This includes chemical fumigation, natural fumigation, and ventilation. The second column of each model reports results conditional on storage.

Table 4.7: Regression results of the probability of experiencing a loss and the total share lost; teff value chain in Ethiopia

		Ethiopia			
		Probit		GLM	
Socio-economic variables	Male producer	0.086	0.059	0.023	-0.010
		(0.060)	(0.069)	(0.057)	(0.071)
	Age of producer (in 10 years)	0.000	0.000	0.002	0.001
		(0.003)	(0.003)	(0.002)	(0.002)
	Education: Primary (vs no education)	0.026	0.007	0.026	0.013
		(0.021)	(0.021)	(0.016)	(0.025)
	Education: Secondary or higher (vs no education)	0.049	0.023	0.027	0.009
		(0.035)	(0.035)	(0.031)	(0.029)
	Experience in cultivation of teff (in 10 years)	-0.007	-0.004	-0.033	-0.021
		(0.031)	(0.030)	(0.022)	(0.020)
Market	Time to reach market (in 10 hours)	1.07	0.932	0.813**	0.881**
		(0.734)	(0.776)	(0.385)	(0.409)
Production	log(Total production teff)	0.056*	0.072**		
		(0.029)	(0.030)		
	Improved seeds (dummy)	0.008	-0.008	-0.016	-0.013
		(0.042)	(0.046)	(0.036)	(0.040)
	Resistant variety	-0.026	-0.049	-0.030	-0.048
		(0.038)	(0.037)	(0.043)	(0.050)
	Number of different inputs applied[a]	0.018	0.017	0.046	0.033
		(0.035)	(0.031)	(0.031)	(0.029)
	Number of production activities done mechanically[b]	-0.204***	-0.112	-0.149**	-0.060
		(0.074)	(0.076)	(0.075)	(0.093)
	Hired labor for harvest	-0.008	-0.005	-0.005	-0.023
		(0.062)	(0.056)	(0.039)	(0.042)
Post-harvest	Storage dummy	-0.011	0.000	0.058	0.000
		(0.183)	.	(0.154)	.
	Nb of post-harvest activities[c]	0.047	0.043	0.049	0.076***
		(0.058)	(0.043)	(0.030)	(0.027)
Storage	Storage time (in months)		-0.018		0.001
			(0.011)		(0.006)
	Storage: Granary (dung or basket) vs bag		-0.080**		-0.011
			(0.033)		(0.064)
	Storage: Pit vs bag		-0.055		-0.121**
			(0.070)		(0.051)
	Storage: Traditional dibignet vs bag		-0.062		0.008
			(0.050)		(0.061)
	Number of storage conservation activities[d]		-0.073**		-0.02
			(0.032)		(0.018)
Production problems & limitations to produce high quality (as perceived by the producer)	Climate	0.150***		0.071*	
		(0.029)		(0.042)	
	Pest	-0.033		-0.01	
		(0.077)		(0.095)	
	Knowledge	-0.052		-0.036	
		(0.044)		(0.034)	
	Technology	0.217**		0.355***	
		(0.105)		(0.129)	
	Storage	-0.101		0.040	
		(0.132)		(0.138)	
	Soil	-0.021		-0.017	
		(0.056)		(0.056)	
	Seeds	0.142**		0.114**	
		(0.058)		(0.050)	
Location fixed effects		kebele	kebele	kebele	kebele
Agroecological zone dummies		yes	yes	yes	yes
No. of Obs.		1113	1094	1113	1094

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parenthesis clustered at the district level. a) This includes fertilizers, insecticides, herbicides and fungicides; b) This includes mechanical herbicide and pesticide application, and plowing; c) This refers to cutting, drying, piling, threshing, winnowing, packaging and transport to piling, threshing and/or storage; d) This includes cleaning previous to storage and preparation of storage site. The second column of each model reports results conditional on storage.

Table 4.8: Regression results of the probability of experiencing a loss and the total share lost; wheat value chain in China

		China		
		Probit	**GLM**	
Socio-economic variables	Male producer	0.019	-0.025	-0.031
		(0.056)	(0.015)	(0.025)
	Age of producer (in 10 years)	-0.003	0.000	-0.001
		(0.004)	(0.001)	(0.001)
	Education: Primary (vs no education)	-0.093	-0.027**	-0.019
		(0.112)	(0.010)	(0.026)
	Education: Middle school (vs no education)	-0.125	-0.029**	-0.022
		(0.157)	(0.012)	(0.031)
	Education: Secondary or higher (vs no education)	-0.039	-0.034**	-0.023
		(0.163)	(0.015)	(0.026)
	Experience in cultivation of wheat (in 10 years)	0.021	0.001	0.004
		(0.027)	(0.007)	(0.015)
Market	Time to reach to closest city of 25.000 inhabitants (in 10 hours)	0.051	0.025	0.259***
		(0.161)	(0.038)	(0.096)
Production	log(Total production wheat)	0.073**		
		(0.030)		
	Improved seeds (dummy)	-0.016	-0.010	0.011
		(0.074)	(0.019)	(0.019)
	Number of different inputs applied[a]	-0.006	0.002	-0.005
		(0.039)	(0.006)	(0.011)
	Number of production activities done mechanically[b]	0.001	0.014*	0.017*
		(0.072)	(0.008)	(0.010)
	Hired labor for harvest	0.112***	-0.008	0.005
		(0.032)	(0.011)	(0.018)
Post-harvest	Storage dummy	0.336***	0.027***	0
		0.098	0.009	.
	Nb of post-harvest activities[c]	-0.009	-0.014***	-0.020*
		0.045	0.005	0.011
Storage	Storage time (in months)			0.009***
				(0.003)
	Storage location: Bag in House vs Bulk in House			-0.024**
				(0.012)
	Storage container: Open air vs Bulk in House			-0.012
				(0.021)
	Storage container: Silo vs Bulk in House			-0.041**
				(0.017)
	Storage conservation activity: fumigation			-0.021
				(0.017)
Production problems & limitations to produce high quality (as perceived by the producer)	Climate	-0.019	-0.006	
		(0.071)	(0.010)	
	Pest	0.291**	0.071**	
		(0.135)	(0.030)	
	Knowledge	0.050	0.002	
		(0.078)	(0.012)	
	Technology	0	0.005	
		.	(0.015)	
	Excess weed	0.000	0.058***	
		.	(0.019)	
	Crop lodging	-0.016	0.016	
		(0.102)	(0.015)	
	Market	0.000	0.030	
		.	(0.021)	
Location fixed effects		township	township	township
Agroecological zone dummies		yes	yes	yes
No. of Obs.		115	911	441

Note: Conditioning on storage predicts failure perfectly. *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parenthesis clustered at the county level. a) This includes fertilizers, insecticides, herbicides and fungicides; b) This includes mechanical land preparation, planting, fertilizer application, chemical application and harvesting; c) This refers to cutting, bundling, stacking, hulling, packing, transport, drying, and cleaning. The second column of each model reports results conditional on storage.

Mechanization and technology in production and post-harvest activities

Surprisingly, these have negative correlations with loss across value chains and countries, highlighting the importance of adequate knowledge. In particular, the number of machine-driven activities, including cleaning, sowing, herbicide application, pest control, fertilizer application, and harvest, correlates with respectively about 8 and 20 percentage points less likelihood of a loss in the bean value chain in Honduras and the teff value chain in Ethiopia, and with 3 to 5 percentage points reduced share of food loss in the potato value chain in Peru and the maize value chain in Mozambique. On the other hand, the number of machine-driven activities correlates with increased losses in the Ecuadorian potato value chain (16 percentage points more likelihood of a loss), Guatemalan maize value chain and Chinese wheat value chain (respectively, about 3 and 15 percentage points more share of produce loss).

The mechanization of harvesting tools considerably affects losses. For example, traditional hoes damage potatoes during the harvest. In Peru, new mechanized tools are used to reduce this damage: the use of both the tractor and the "lampa" has a correlation with a significant reduction of the share of potatoes lost during harvest (all else equal, 30 percentage points less). Similarly, in Mozambique, mechanization reduces the likelihood in incurring in a loss of maize (- 4 percentage points). The potato value chain in Ecuador is more traditional, with very few mechanical tools used. Finally, resistant varieties or Improved seeds have a consistent correlation with reduction of losses, and the correlation is significant in the potato value chains in Ecuador and Peru, and the maize value chains in Guatemala and Honduras (between 4 to 8 percentage points less likelihood of a loss and around 3 percentage points less share of produce loss).

Mechanical post-harvest activities are not widespread, with mechanical drying, winnowing, and threshing activities being observed only in the maize and bean value chains in Honduras and Guatemala. Increased mechanization in the drying and winnowing activities reduce loss in the bean value chain in

Guatemala and the maize value chain in Honduras but mechanical threshing increases losses in the bean value chain in Honduras and the maize value chain in Guatemala. Farmers likely incur grain damage, cracks, and lesions when mechanically (instead of manually) stripping the grain from the plant. This makes the grain more vulnerable to insects and visually less appealing.

Most of the harvesting is still performed manually in these countries, making them labor intensive and slow. During the harvest season, countries may face labor shortages, which can be resolved by hiring external labor. The hired labor force is mostly correlated with reduction of losses. This is significant in the bean value chains in Guatemala and Honduras (between 4 and 19 percentage points less likelihood of a loss), the potato value chain in Ecuador, and the maize value chain in Mozambique (between 4 and 8 percentage points less share of produce loss).

The lack of adequate storage techniques

This can lead to food loss due to biotic factors (pest, insects, fungi, and rodents), abiotic factors (rain, temperature, humidity), or spillage when filling or emptying storage space. Potato producers in Ecuador and Peru rarely store their product. But other products included in our survey are grown seasonally, and after harvest the grains are stored as food reserves and seeds for the next season. All else equal, post-harvest storage has a correlation with increased loss in the bean value chains in Guatemala and Honduras, the maize value chain in Mozambique, and the wheat value chain in China (across all value chains and countries, we see between 14 and 37 percentage points more likelihood of incurring in any loss, and between 3 and 13 percentage points more share of produce loss). In Honduras and China, the storage duration correlates with increased share of produce loss (between 0.9 and 1.1 percentage points more). In most countries, grains are generally stored as bulk or in bags in the farmer’s house or simple granaries built with locally available materials (mud and bricks). Improved storage infrastructure (silos or improved granaries) is associated with mitigation of these risks in the bean value chain in Guatemala, the maize value chain in

Guatemala and Honduras, and the wheat value chain in China (between 18 and 31 percentage point less likelihood of incurring in a loss; and 2 to 16 percentage points less share of produce loss). It is also the case in the teff value chain in Ethiopia, where “pits” are used instead of other traditional storage facilities. This is because they reduce the probability of insect infestation and mold growth. Storage conservation activities, such as chemical or natural fumigation, or increased ventilation, are correlated with reduced losses of stored food in Honduras and Ethiopia.

Unfavorable climatic conditions, pests, and diseases

These are often mentioned as problems farmers face during production. In Honduras, Guatemala, Mozambique, and Ethiopia, unfavorable climatic conditions, as assessed by farmers, are positively correlated with the likelihood of incurring losses and the share lost (all else equal, climatic conditions respectively are associated with 8 to 18 more percentage points likelihood of food loss, and 3 to 7 more percentage points share of produce loss). In addition, farmers mention pests, diseases, and rodents as major production problems.

4.5 Discussion

We break down our results by five groups of potential origins of food loss and compare them with those of other studies.

Socio-economic characteristics

Our results on the impact of gender on food loss are contradictory. Similar findings have been reported by Chegere (2018) that being male is correlated with reduced losses in the sub-Saharan maize value chain. On the other hand, Folayan et al. (2013) and Ngowi et al. (2019) find that being male is correlated with an increase in losses in the maize value chain in Nigeria and Tanzania. Our results that age, education, and experience tend to be negatively correlated with losses is in line with most of the literature: Ahmed et al. (2015), Maziku (2020) and Paneru et al. (2018) find that experience and education have a negative correlation with losses. Ambler et al. (2018) and

Ansah et al. (2017) find the same negative result for age. Basavaraja et al (2007), Gebretsadik et al. (2019), Khatun et al. (2019), and Shee et al. (2019) find a negative association between education and losses. Kuranen-Joko et al. (2017).

Yet, in some contexts, they seem to have opposite correlations. Education has been found to have a positive correlation with losses in the maize value chain in Mozambique (Ansah et al., 2017; Doki et al., 2019). Ngowi et al. (2019) and Shee et al. (2019) analyze the maize and white-fleshed sweet potato value chains in Tanzania and Uganda, and find that age is positively correlated with losses.

Market access

In line with most studies, our results find that transportation is positively associated with food loss due to the additional costs imposed on the farmer and complexities in transporting the food commodities. Chegere (2018) finds that maize farmers in sub-Saharan Africa experience more losses if they transport maize themselves. Gebretsadik et al. (2019) observe increased losses due to the distance between the farm and the residence, and the distance between the stacking place and the threshing place. The mode of transportation positively affects post-harvest grain losses in sesame in Ethiopia (Gebretsadik et al., 2019), maize in Tanzania (Ismail and Changalima, 2019) and sweet potato in Uganda (Shee et al., 2019). These findings directly support previous studies' findings, which highlight the importance of road to reduce food loss across the value chain (Rosegrant et al., 2015).

Mechanization and technology in production and post-harvest activities

The literature is full of conflicting effects of mechanization and adoption of technology on reducing food loss. For example, Ahmed et al. (2015) find that losses are lower for fruits picked with scissors, rather than by hand, when it comes to the Pakistani kinnow value chain. Khatun et al. (2019) also find that shifting from traditional packaging to improved packaging decreases losses in the eggplant value chain in Bangladesh. Our findings on the Peruvian potato value chain are consistent with those findings. On the contrary, Shee et al. (2019) find that mechanization of harvesting considerably increased losses for maize and sweet potatoes in Uganda. These mixed results highlight the importance of adequate knowledge and training that must accompany the use of new tools.

The lack of adequate storage techniques

Post-harvest storage significantly increases the likelihood of losses (Ngowi et al., 2019), and our results on storage techniques confirm this finding by previous studies on food loss. Previous studies have also found that losses significantly increased during longer storage period (Aidoo et al., 2014; Ismail et al., 2019). At the same time, the lack of modern storage facilities is positively correlated with losses (Folayan, 2013; Maziku, 2020; Paneru et al., 2018), demonstrating that improved storage infrastructure mitigates the risks of food loss.

Unfavorable climatic conditions, pests, and diseases

Our finding that unfavorable climatic conditions increase the likelihood of incurring losses is in line with the literature. In particular, Ambler et al. (2018), Gebretsadik et al. (2019), and Maziku (2020) find this correlation when it comes to post-harvest rainfall in the value chains of maize, groundnuts and soy in Malawi. This correlation was also found between wind and rain during harvesting to threshing time in the sesame value chain in Ethiopia; between rain and post-harvest activities in the maize value chain in Tanzania. Our results confirm previous findings, highlighting that the lack of rainfall causes significant pre-harvest losses for crops like potato, maize, beans, and teff in Ecuador, Peru, Honduras, Guatemala, and Ethiopia (Delgado et al., 2021a).

4.6 Conclusion

Identifying the causes and costs of food loss across the value chain is critical for setting priorities for action. Analyzing the factors affecting food loss at the micro-, meso-, and macro-levels can help identify effective reduction interventions.

Our results show that socio-economic characteristics, such as education and experience, positively correlate with reduction of losses. In four out of the nine value chains studied, the association of education and the number of years a producer has grown specific crops with reduction of losses is significant. Unfavorable climatic conditions are positively correlated to losses in most countries; and major production problems mentioned by farmers are pest, diseases, and rodents.

The techniques that constitute proper handling of produce may vary from case to case. For example, mechanical production activities increase losses in Ecuadorian potato value chain, Guatemalan maize value chain, and Chinese wheat value chain. On the contrary, it was traditional harvesting tools, like hoes, that accounted for an important share of losses in Peru's potato value chains. Likewise, in Mozambique, mechanization reduced losses of maize. The number of inputs applied follow similar mixed trends. This emphasizes the critical need for knowledge and training in addition to adopting technology to effectively decrease losses. The lack of appropriate storage techniques is consistently correlated with higher losses; longer storage durations tend to exacerbate the losses. Improved storage infrastructure can mitigate these risks.

Finally, the cost of accessing markets have a significant correlation with increased losses in five out of the seven countries. This indicates that the absence of markets represents critical limitations for farmers. This directly supports the findings of previous studies, which show the importance of better roads to reduce food loss across the value chain.

While there are commonalities, food loss is very context specific. The heterogeneity suggests that policies aiming at the reduction and prevention of food loss need to be developed with specific commodity and context in mind.

More research is needed to identify the drivers behind losses. For example, disentangling the role of farmers' demography, education, producer experience, and gender is needed. It is necessary to analyze the factors related to production — access to technology and agricultural assets, infrastructure — geography and climate. Furthermore, experimental studies on different storage techniques and mechanizations, and targeted training programs can confirm the effectiveness of specific interventions on food loss reduction.

These findings should be used to inform policies. Governments should ensure that public and private sector investments facilitate reductions in food losses by identifying the main causes of food loss in specific commodities and contexts. Such investments cover a broad gamut of areas related to food systems, including food safety, education, and infrastructure, regulations and standards, and market failures.

Smallholders, who produce only small surpluses, often face substantial market failures that contribute to food loss. Public sector investment can address some of these shortcomings, such as the need for appropriate storage facilities, efficient transport systems, policies that improve access to credit, support for market incentives for improved food safety as in the case of aflatoxins, and access to crop varieties resistant to weather shocks. Reducing food loss can generate profits. For example, choosing appropriate crop varieties, dealing with pre-harvest pests, and making processing and retail decisions may be best addressed by the private sector. There is a clear need to build an evidence base on the efficacy of these reduction interventions, particularly when combined with training, changes in handling practices, and access to finance.

Chapter 5

An a priori analysis: the potential role of soil perception and soil variability in smallholder farmers' low adoption rates of agricultural practices in Central America

Food systems are under pressure to produce more food of higher quality while reducing the pressure on the natural resources. Currently 30% of the planet's total land is degraded, especially in areas where smallholder farmers are located. Agricultural extension may help to stimulate farmers to adopt sustainable practices. However, farmers' perception of soil quality and soil variability may hamper the adoption of theses interventions. This paper aims to carry out an ex ante analysis to determine to what extent soil perception and soil variability limit adoption with the final goal to design better policies to crop productivity. This paper measures the gap between smallholder farmers' perceptions of their soil characteristics and the soil variability. Smallholder farmers in Central America have significant misperceptions of soil characteristics. Improving farmers' understanding of soil quality is a necessary condition to accelerate the adoption of technological packages, such as fertilizers and seeds. In addition, reducing policymakers' information gap with respect to the real needs of farmers will make policies more effective, resulting in higher adoption rates of new technologies and increased productivity. This could also lead to food loss reduction that happens at the pre-harvest level.

This chapter is based on:

Delgado, L., Stoorvogel, J. 2021. An a priori analysis: the potential role of soil perception and soil variability in smallholder farmers' low adoption rates of agricultural practices in Central America. Submitted to Journal of Rural Studies.

5.1 Introduction

Food systems must be transformed to provide enough quantity of healthy food for everyone in a sustainable way, including those involved in the production chain, while dealing with the dynamics of local and global economies and environment. Transforming global food systems requires a combination of research, policies and extension services to manage complex trade-offs. One of the challenges of agricultural extension is low adoption rates. Suffice it to say, it is important to understand what is and is not working, and provide additional information to improve efficiency and effectiveness of policies. This insight is necessary for informed decision making, including on trade negotiations and targeted agricultural policies. Soil management is an essential element of food systems. It is even more important today given that 30% of the total global land is degraded (Sterk and Stoorvogel, 2020) and that it plays a critical role in the adoption decisions farmers make on the use of fertilizers and water conservation practices, among others (Pham et al., 2021).

The literature shows that there is a problem of low adoption of interventions in agriculture (Hermans et al., 2021). Lambrecht et al. (2014) identified the three stages of the adoption process. First, awareness when the farmer becomes aware of the existence of new technology. Second, try-out when the farmer, being aware of a new technology, has access to more information to decide whether to use the new technology. Finally, there is adoption when the farmer decides after the try-out if the profitability is high enough to continue to use it.

The low adoption rate has been widely studied and different reasons have been identified. First, farmers' characteristics like age, training, and social capital influence adoption rates (Feder and Umali, 1993; Abadi Ghadim and Pannell, 1999; Pham et al., 2021). Older farmers are more risk averse and therefore it is less probable that they will adopt new technologies or practices. Neil et al. (2001), Sureshwaran et al. (1996), and Arellanes (1994) found negative relations between age and adoption of soil protection measures. Feder and Umali (1993) found that "older farmers are less likely to use soil conservation practices because of their shorter planning horizons and the less than perfect capitalization of yield changes in land prices.” With regards to experience, farmers who have previously experienced other innovations may have lower levels of uncertainty about the performance of innovation and therefore more likely to adopt a new technology (Abadi Ghadim and Pannell, 1999; Foguesatto et al., 2020). On education, Lambrecht et al. (2014) did not find any effect between education level. However, Feder and Umali (1993), Pedzisa et al. (2015), and Foguesatto et al. (2020) found that education has a positive impact on the adoption of soil conservation technologies.

Second, plot characteristics also have an important effect on adoption rates. Lambrecht et al. (2014) found that the quality of the land matters. For example, sloped plots decreased the chances of farmers trying out new technologies. In addition, soil quality seems to affect the probability of adoption. Clay et al. (1998) showed that “farmers tended to invest in conservation efforts on slopes of medium grade” in Rwanda. Shively (1997) showed that “adoption of hedgerows was less likely on parcels with greater soil depth or on older, exhausted parcels” in the Philippines. Arellanes (1994) and Bonnard (1995) considered the roles of slope and soil quality in the adoption of improved soil management practices. Foguesatto et al. (2020) found that land slope, soil colour, soil depth, soil erosion severity, soil fertility, soil type were significant factors influencing the adoption of sustainable agricultural practices (SAP).

Third, there are reasons linked to behavioural characteristics of the farmers, such as their level of risk aversion, intertemporal discount rates, and time preferences. Abadi Ghadim et al. (1999) found that personal discounts rates and time preference influenced farmers’ adoption. Duflo et al. (2011) found that farmers may procrastinate, postponing fertilizer purchases until later periods, when they may be too impatient to purchase fertilizer. Higher discount rates lead to lower adoption rates. Mansfield (1961) concluded that the adoption of innovations is determined by the economic attributes of farmers.

Fourth, access to markets and to capital and credit influence the adoption rates. Feder and Umali (1993), Doss (2006), and Lambrecht et al. (2014) found that capital and credit have a positive effect on adoption rates. According to Chikowo et al. (2014), the data from Tittonell et al. (2005) suggests that proximity to markets influences fertilizer use. Takahashi et al. (2020) cites Suri (2011), who suggested that the travel time to seed and fertilizer distributors is a constraint for adoption. Doss (2006) and Foguesatto et al. (2020) found that there was a positive correlation between access to markets and adoption.

Fifth, the distance to innovators or social networks can affect adoption. Abadi Ghadim et al. (1999), Lambrecht et al. (2014), and Pham et al. (2021) found that the physical distance to and contact with the nearest adopter of innovation influence the adoption of new technologies.

Sixth, farmers' economic decisions regarding the allocation of limited resources affects adoption. If a farmer owns more than one field, typical of smallholders in developing countries, he or she may not invest equally in each field, because of their limited natural, human, and economic capital. As a result, some fields may be well protected against degradation, while others may be left vulnerable to erosion and degradation (Sterk and Stoorvogel, 2020). Feder and Umali (1993) and Pham et al. (2021) found that farm sizes have a positive influence on the adoption of conservation practices; Feder and Umali (1993) also found that farmers who rent a plot are less likely to adopt new conservation technologies. However, they also found "renters were more likely to use conservation tillage than full owners."

Finally, access to information and the quality and quantity of extension services are crucial on adoption decisions (Doss, 2006; Lambrecht et al., 2014; Pedzisa et al., 2016; Foguesatto et al., 2020; Takahashi et al., 2020; Pham et al., 2021).

All of the above seven reasons focus on the following: existing assets (human capital and land); access to economic and social resources (networks, credit, markets, characteristics of the plot, and supply of extension services);

behavioural issues (rate of risk aversion and intertemporal discount rates). But they fail to clarify whether they are the cause of low adoption rates. Sometimes low adoption rates occur because the technologies proposed are not relevant to the producer or plot characteristics or the problems producers face. Some technologies that are successfully developed in the research lab can fail when they are implemented on the farm because the conditions are different (Chikowo et al., 2014). Another problem is that most of the time, researchers only look for the implementation of a single technology, which does not necessarily contribute to an overall goal of increasing yields or decreasing production costs (Chikowo et al., 2014; Takahashi et al., 2020). Also, researchers fail to recommend the adoption of integrated farm management systems. Sometimes a new technology is recommended to resolve a problem that cannot be resolved by a technology. Therefore, it is important to invest the time to identify the problem and other solutions.

This paper studies soil perception of farmers and soil variability to evaluate in an ex-ante manner whether these factors play a role in improving the adoption of agricultural interventions. This paper examines the differences in perception between a farmer and a proxy to the scientist (such as a survey taker or enumerator trained by scientists) when it comes to environmental characteristics, including soils. We argue that understanding the real problem that needs to be resolved with the adoption of a new technology or practice is central to increasing adoption rates. Identifying the problem — specifically providing information to the farmer and policymakers so that they understand and perceive the real problem — will determine the adoption rates of intervention. Soil perception and soil variability has a critical role to play here. In the case of soil perception, the farmer does not necessarily perceive problems like soil degradation. Naturally, in the farmer’s mind, there is no need to adopt a new technology to mitigate a problem that does not exist (soil degradation). In the case of soil variability, an intervention may be appropriate for a certain region, but not for the specific conditions of a specific plot of a farmer.

5.2 Materials and Methods

Study area

Central America is one of the most vulnerable regions to disasters due to its geographical location, high climate variability, exposure to extreme hazards and the institutional and socio-economic weaknesses of its population (FAO, 2015). This paper studies areas in the regions of Guatemala and Honduras that are part of the Dry Corridor.[47] The Dry Corridor experienced significant droughts, including El Niño and La Niña. As a result, there are more than 3.5 million people in need of humanitarian assistance (FAO, 2016). Fraga (2020) cites studies that showed "the intensity and duration of these climatic events are amplified due to human-induced degradation of ecosystems, including high rates of deforestation and soil erosion" (van der Zee et al., 2012; Magrin et al., 2014; ECLAC, 2015; Calvo-Solano et al., 2018). There are two growing seasons for grains: *Primera* (April-August) and *Postrera* (September-November). The climate is mostly tropical throughout the area, although temperatures are lower at higher altitudes in the highlands. In the areas that belong to Guatemala and Honduras, maize and beans are the two most important crops.

Guatemala is the third largest country in the tropical zone of Central America, with mountainous regions surrounding the total cultivable area. A vast share of 77% of the country's arable area is used for agriculture and forestry (FAO, 2018). According to MAGA (2013), 9% of the total surface area of the country is part of the Dry Corridor (Fraga, 2020). In Guatemala, this study was implemented by the departments of Chimaltenango, Escuintla, Guatemala, Quetzaltenango, Sacatepéquez, San Marcos, Sololá, and Totonicapán. These departments were selected because they are part of the

[47] The Dry Corridor is a tropical dry forest region on the Pacific side of Central America. The Dry Corridor is characterized by irregular rainfalls. It has become one of the most susceptible regions to climate change and variability in the world. The countries forming the largest part of the Dry Corridor are Guatemala, El Salvador, Honduras, and Nicaragua (FAO, 2017).

Dry Corridor and also because the project helped to develop a soil map (1:50,000),[48] allowing access to detail information for soils.

Honduras, the second largest country in Central America, is bordered by Guatemala to the west, El Salvador to the southwest, and Nicaragua to the southeast. The Dry Corridor is located in the western, central and southern areas, occupying around 27% of the total area of the country (INVEST-H, 2014). According to Silva (2009); in Honduras, 32% of the area is used for crops and livestock (INE, 2006). This paper studied the areas in the departments of Choluteca, Copan, El Paraiso, Francisco Morazán, Intibucá, La Paz, Lempira, Olancho, Santa Barbara, and Valle. This departments were selected because they are part of the Dry Corridor, the poorest area of Honduras.

Survey design to measure perceptions of farmers

Self-evaluations, such as observational measurement, have important implications for decisions made by individuals and policymakers, but they are typically not assessed carefully. Yet, comparison is inherently a dynamic process that could be affected by systematic or random circumstances. Moreover, self-evaluations are a personal process; comparisons occur at different times on a range of dimensions, with consequences that can vary by context and availability of information. Research across social and clinical psychology has implemented methods to assess comparisons naturally, involving intensive, repeated assessments of comparison occurrence, characteristics, and consequences. However, very little evidence exists on the potential size of the measurement error behind those assessments. This paper uses a simple empirical methodology as an approximation to identify

[48] In 2006, the Ministry of Agriculture and Livestock (MAGA) of Guatemala, started a project to develop a semi-detail soil map (1:50,000) in eight departments of the country. The objective of this map is to increase the productivity of the soils by finding out more about their characteristics (resources, limitations), and which crop and technology might be suitable. This paper shows adequate conservation practices for the soils in the area. At the time of research, data from only three departments were available (Chimaltenango, Sacatepéquez, and Sololá).

the level of magnitude of the potential errors in self-evaluations or perceptions by farmers. The methodology consists of a sequential process, in which farmers are asked detailed questions, and trained survey takers then also respond to the same questions. This allows comparison between a farmer's self-evaluation of certain characteristics of their plots and the same evaluation by survey takers.

The measurement of soil analysis and perceptions consisted of a series of questions answered by both the farmer and the survey taker. All the questions on perceptions were based on observable variables, like land cover, slope, and presence of organic matter, surface stoniness and texture. For each farmer, an enumerator was identified for all the plots, the area, and the crops (by plot). If the producer managed more than two plots, he/she chose the more important plot for bean production for *postrera* 2017 in Guatemala and Honduras. The survey sought answers plot by plot. The producers answered the questions first, followed by the enumerators answering the same questions. As explained in the following sections, the enumerator described options for answers to the producers using images.

In each country, the enumerators were trained for five days on scientific criteria to identify the characteristics of the soil. This was done to homogenize the concepts and criteria on land cover, slope, soil organic matter content, and surface stoniness, as well as to define the presence of different materials in soil, like sand, clay, and silt. Additionally, the enumerators were trained on using the equipment to measure soil pH and EC. During the training, the enumerators studied all the information on paper. After that, they worked on practical cases in groups. This was followed by group discussions to dispel any uncertainties. Before fieldwork started, the enumerators implemented a pilot and several tests to standardize concepts and criteria on assessing the variables. In Honduras, the authors worked with eight enumerators and two supervisors divided into two groups. In Guatemala, the authors worked with four enumerators and one supervisor. All enumerators had substantial experience conducting agricultural surveys. In Guatemala, the enumerators knew the local language.

The survey asked producers about the characteristics of their agricultural plots and land management. The enumerators at each plot also assessed the characteristics of the same agricultural plots. In addition to land cover, four soil properties that often play a role in soil management and interventions were studied: i) slope is the main causal factor for erosion and can be managed through terracing; ii) soil organic matter contents are important for crop nutrition and the water holding capacity and can be managed by mulching and organic fertilizer; iii) surface stoniness can limit the options for mechanization but is more difficult to manage; iv) soil texture also plays an important role in crop nutrition and the water holding capacity, but it cannot be managed.

The questions were asked in the plot where farmers planted beans in *postrera* of 2017. The questions were multi-choice and close-ended. To minimize any measurement error, the survey was conducted using tablets and the Computer-Assisted Personal Interview (CAPI) SurveyCTO,[49] which was monitored on real time. For each question on perceptions, the enumerator described and showed the answer options using images to make the options easy to understand (Figure 5.1). The options and images were based on the app LandInfo (now a module of LandPKS).

[49] https://www.surveycto.com/

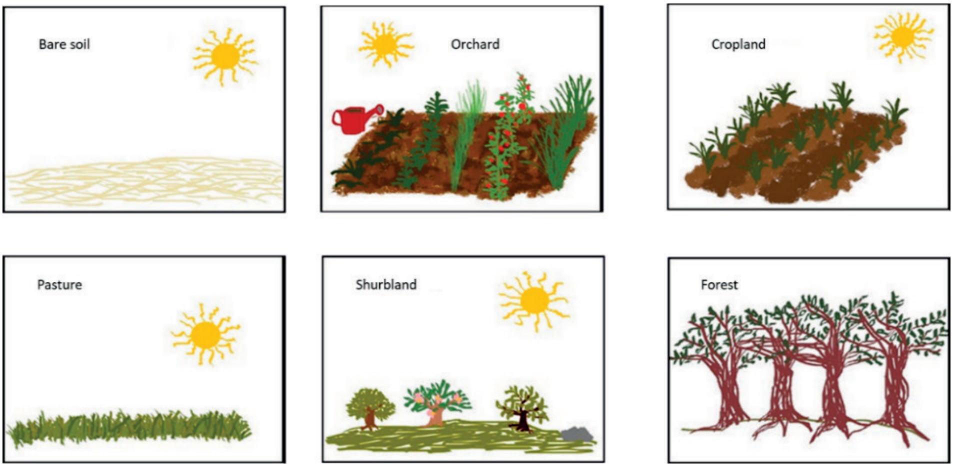


Figure 5.1: Example of how the land cover was showed to producers[50] from the survey conducted by International Food Policy Research Institute (IFPRI) in 2018 in Guatemala and Honduras, as part of the project of the Dry Corridor.

Soil analysis was performed on the agricultural plots where beans were produced. For this purpose, a detailed protocol was developed. The enumerators needed to identify the plot that they would be using for the survey and physically moved to the specific plot. Sometimes the plot was close to the house, but in other cases, the plot was far away. Only plots that were at most 1.5-hour-walking distance away were considered. The analysis was performed on at least five soil samples per plot, depending on the size and shape of the plot. The samples were roughly taken in the four corners and one in the center. As shown in figure 5.2, the samples were not taken on the edges, on the roads, in the ditches, in places of accumulation of materials (brush, fertilizers, pesticides, fungicides), or near the house or a construction site.

[50] Figure 5.1 shows the answer options for land cover exactly as the producers saw them. The enumerators provided the sketches of the plots.

Figure 5.2: Examples of how to distribute the soil samples in the plot from the survey conducted by International Food Policy Research Institute (IFPRI) in 2018 in Guatemala and Honduras as part of the project of the Dry Corridor.

Each sample consisted of the first 10cm of the soil after removing the top layer with litter. Samples were collected with a small spade. Soil fertility was estimated for all samples in terms of soil texture, soil pH, electrical conductivity and soil organic matter. Soil texture was hand estimated according to protocols established in the training. For each soil sample, soil pH and the electrical conductivity (EC in mS) were measured with a 1:2.5 soil-water ratio, using a GroLine HI98131 Combo Tester (Hanna Instruments). The equipment was calibrated after 25 samples.

Sampling

The survey was conducted between March and May of 2018 in Guatemala and Honduras. A random sample of 450 bean producers in Guatemala and 685 bean producers in Honduras were surveyed. This soil survey was part of a larger experiment organized by the International Food Policy Research Institute to improve food loss reduction.

5.3 Results

This section compares the perceptions of the farmer with the observations of the survey taker on: (a) land cover, which refers to the physical land covering on the land you are assessing; (b) land slope, which is the rise or fall of the land surface (FAO, 1985). It helps to understand how rainfall affects the land; (c) soil organic matter, which is the fraction of the soil that is present when plant or animal tissue decomposes (Fenton et al., 2008); (d) surface stoniness, which indicates the soil rocket fragment volume in each plot; and e) soil texture, which indicates the relative content of different particles like sand, silt, and clay in the soil.

Measuring differences between the perception of the farmer and what the trained enumerators identified.

Figure 5.3 shows the different perceptions of land cover, slope, organic matter, and surface stoniness between the enumerators (on the left side) and the producers (on the right side) in Guatemala (left side) and Honduras (right side).

Figure 5.3A (land cover) shows that the perception between enumerators and producers is similar on bare soil and cropland in both countries, and on shrubland in Honduras. Major differences in perception are with the shrubland option in Guatemala. The producers see more bare soil than the enumerators. This is also true in the plots where the enumerators see more crops in Guatemala.

Figure 5.3B (slope) shows a huge variance (difference) in the perception between enumerators and producers. The producers see their plot with a less steep slope in both countries. When asked if the plot has different slopes, the enumerators chose the option that occupies more area in the plot.

Figure 5.3C (organic matter) shows the differences between enumerators and producers. The enumerators measure the presence of organic matter based on the color of the soil (darker means more presence). In both countries, the producers underestimate the presence of organic matter in their plots.

Figure 5.3D (surface stoniness) shows little difference in the perception of two parties. But in both countries, the perception of the presence of stones is lower on the producer side.

Guatemala **Honduras**

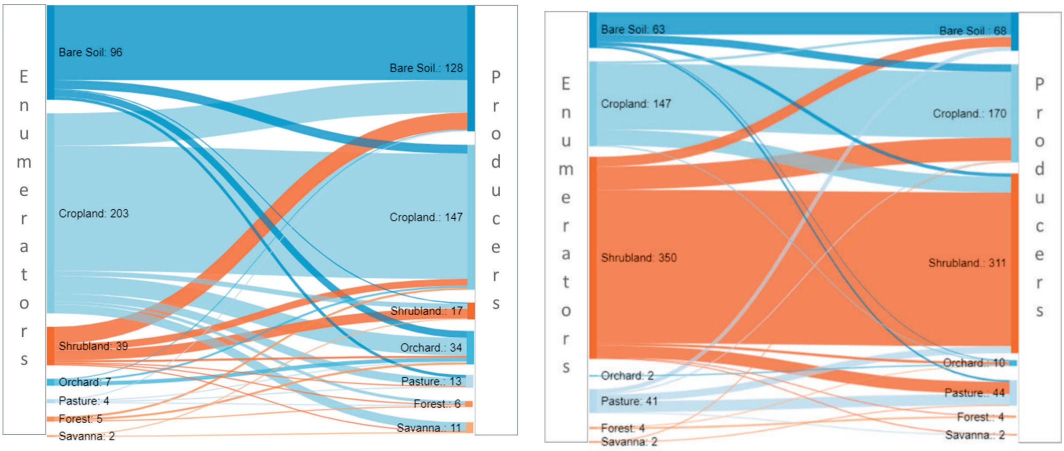


Figure 5.3a

Guatemala **Honduras**

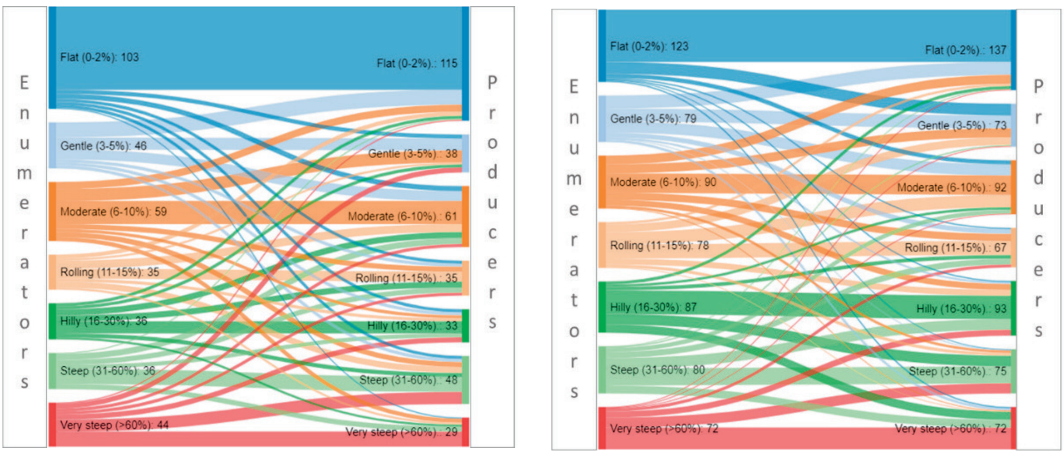


Figure 5.3b

Guatemala **Honduras**

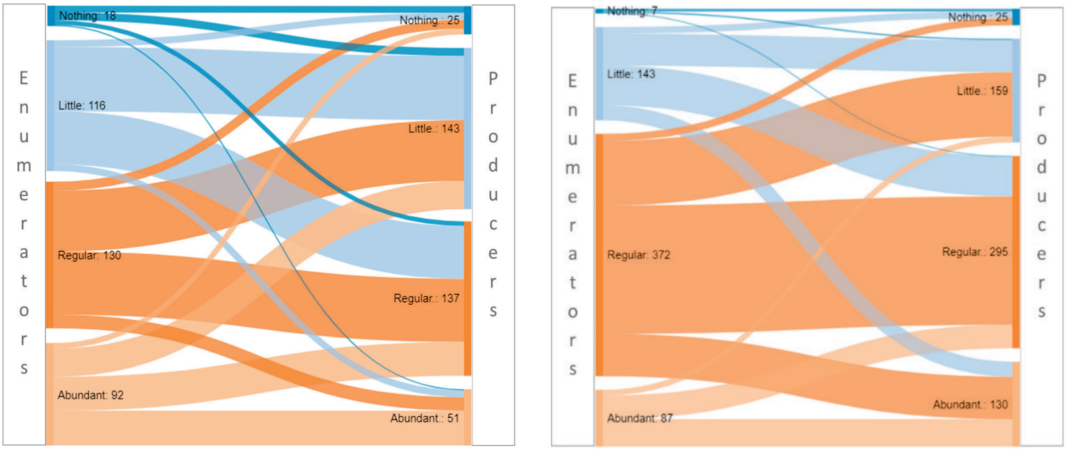


Figure 5.3c

Guatemala **Honduras**

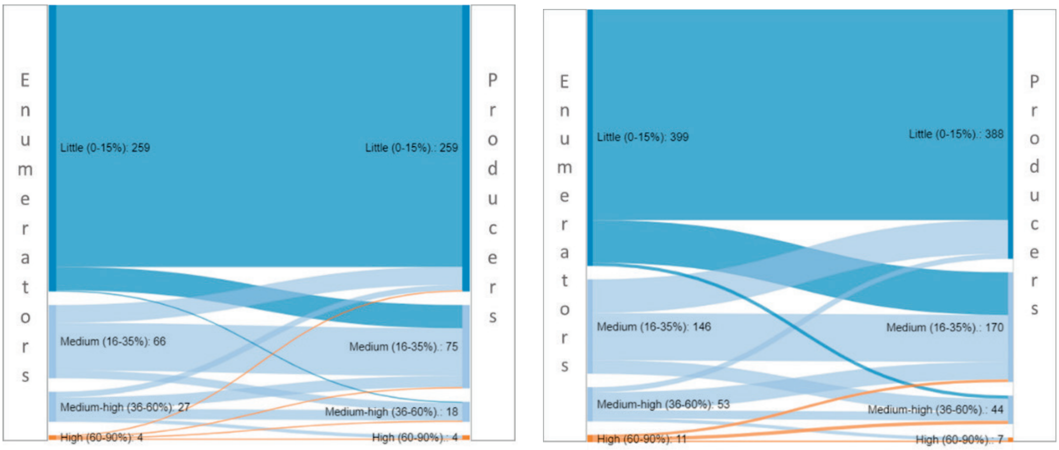


Figure 5.3d

Figure 5.3: Observations of Land cover (A), Slope (B), Soil organic matter content (C) and Surface stoniness (D) on agricultural plots in the study area by enumerators and farmers in Guatemala (left) and Honduras (right)

Figure 5.4 shows a comparison between the perception of the enumerator on the organic matter content (on the left side) and the producer perception of the fertility of each plot (on the right side) in Guatemala (left side) and Honduras (right side). These graphs show that 90% of the producers consider their plot fertile. As mentioned before, the presence of organic matter was identified using the color of the soil (dark colors means presence). Because of the variation of the results, it looks like the perception of fertility of the plots is not only related to the presence of organic matter, but also to more yields.

In Figures 5.5 and 5.6, the abundance of materials in the soil measure is compared by feeling the texture by the enumerators and the perception of the producers. For the first material in abundance (Figure 5.5), in Honduras, the predominant materials are sand and silt both for enumerators and producers; in Guatemala, the presence of the three materials is well distributed, finding more differences in perception. In the case of the second material in abundance (Figure 5.6), more differences were found between enumerators and producers in both countries. Texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through soil (FAO, 1985).

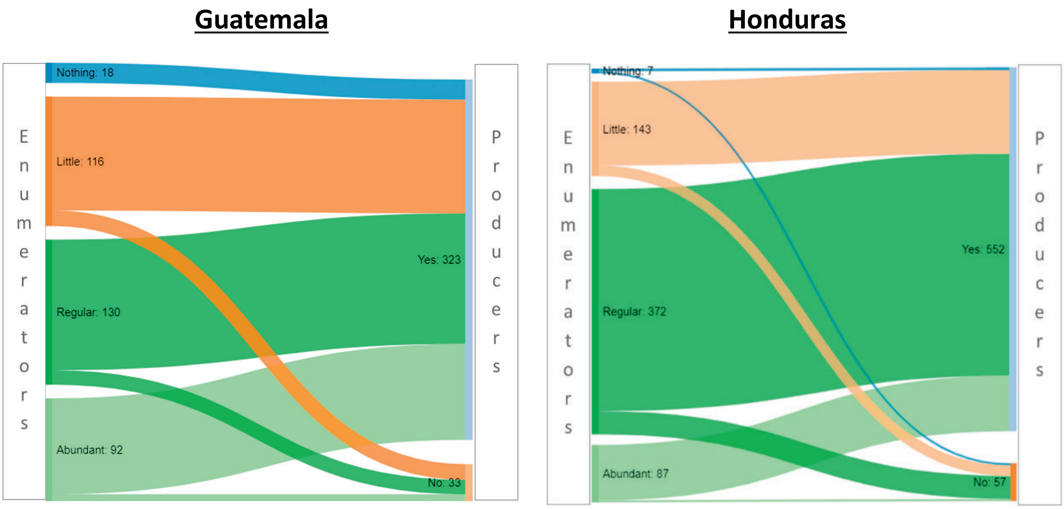


Figure 5.4: Comparison between organic matter content by the enumerators and perception of fertility by the producers in Guatemala (left) and Honduras (right)

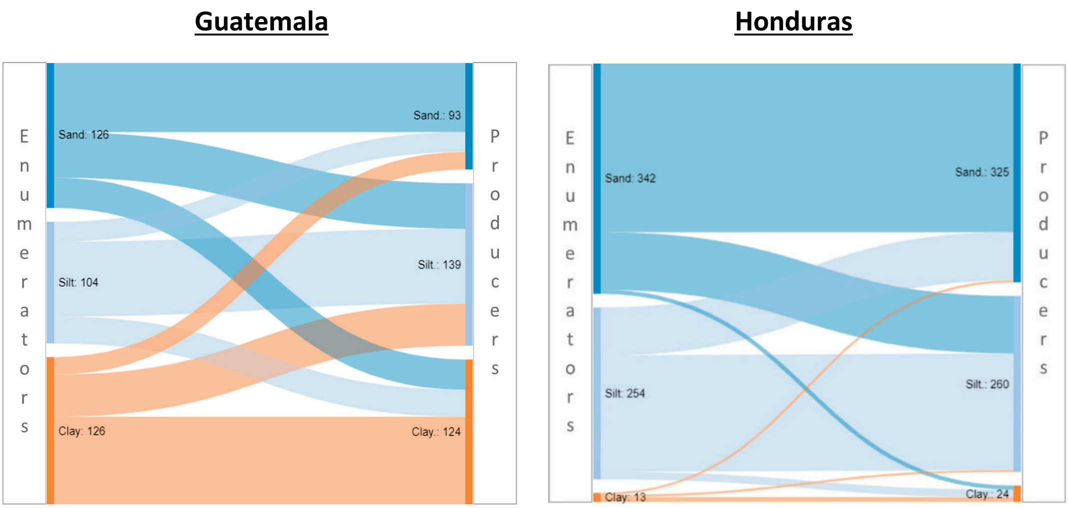


Figure 5.5: Comparison of the first material in abundance in the soil by the enumerators and producers in Guatemala (left) and Honduras (right)

Guatemala **Honduras**

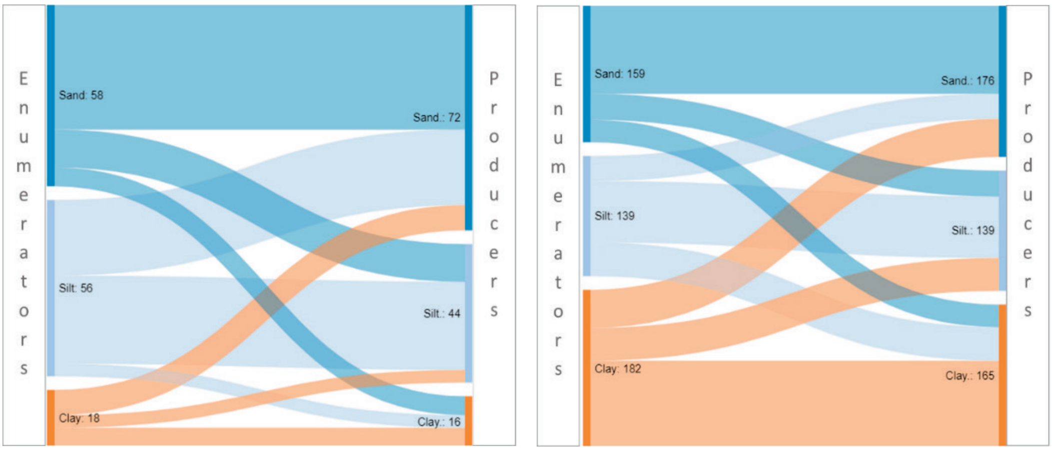


Figure 5.6: Comparison of the second material in abundance in the soil by the enumerators and producers in Guatemala (left) and Honduras (right)

Differences in perception between farmers and enumerators showed a similar pattern in each of the dimensions measured in Guatemala and Honduras (Table 5.1). In both countries, the observations of farmers and surveyors differ significantly for all the variables (p-value <0.001) when applying a a Pearson's chi-squared test. Cramer's V showed a low relation between the perceptions in all the variables.

Table 5.1: Similarity in observations, Chi square and the Cr'mer's V relation between enumerators and farmers for different plot characteristics

Variable	Guatemala			Honduras		
	Similarity	Chi-square	Cramer's V	Similarity	Chi-square	Cramer's V
Land cover	60%	253.332	0.34	73%	0.001	0.53
Slope	47%	321.515	0.39	45%	624.029	0.41
Soil organic matter	41%	64.919	0.25	48%	108.271	0.24
Surface stoniness	79%	239.820	0.47	68%	260.469	0.38

Note: Pearson's chi-squared test rejects equality with prob= 0.000 of perceptions of farmers and surveyors.

Measuring the pH and its variance to see consistency with government technological packages

Soil pH, measured in a soil-water solution, is a measure for the acidity and alkalinity of the soil (Harmonized World Soil Database, 2009), and it influences the solubility of nutrients. Soil electrical conductivity (EC) measures the amount of salts in soil (salinity of soil). It affects crop yields, nutrient availability, crop suitability, and activity soil microorganisms (USDA-NCS, 2019). In both countries, the electrical conductivity was between 0 to 2 (non-saline). As previously explained, soil analysis was performed in all the plots of beans surveyed to measure pH and electrical conductivity.

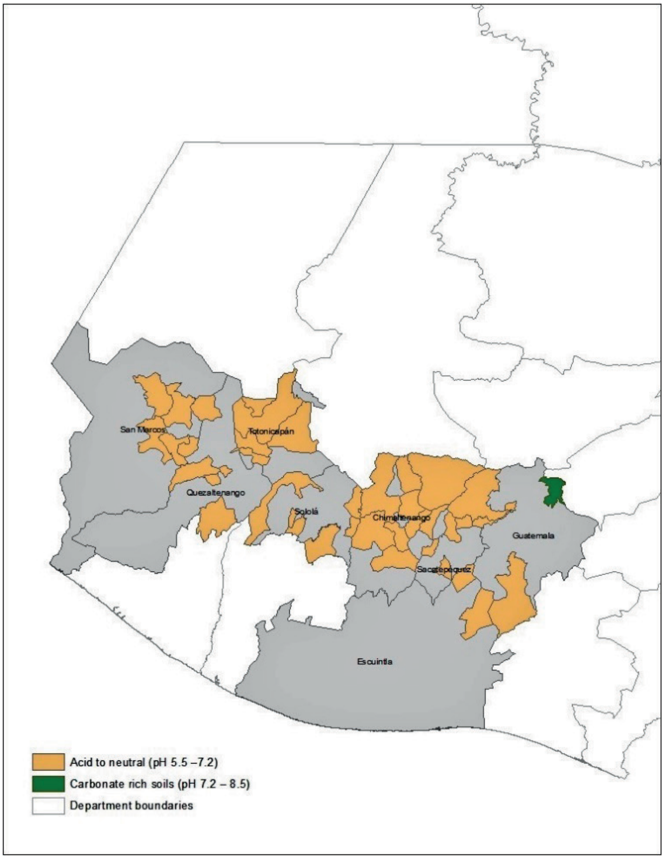


Figure 5.7: Soil pH classes by municipality in Guatemala

Figures 5.7, 5.8A and 5.8B showed the soil pH calculated by municipality and categorized with the official classification used in the harmonized world soil database of 2012. In Guatemala, almost all the municipalities where soil samples were made have a pH acid to neutral (5.5 to 7.2). Only the municipality of San Jose del Golfo in Guatemala department has an average pH between 7.2 to 8.5, which means that this municipality is classified to have carbonate-rich soils (Figure 5.7). In this municipality, 60% of the sampling plots had a pH between 7.2 to 8.5, while the other 40% had a pH of 5.5 to 7.2 (acid to neutral soils). As showed in Figure 5.8B, the pH in this municipality had a standard deviation higher than 0.8. The municipality of San Bartolo of Totonicapan department is categorized with a pH of 5.5 to 7.2 (acid to neutral soils). However, it was found that 90% of the plot had a pH between 5.5 to 7.2 (acid to neutral soils), 5.5% had a pH between 4.5 to 5.5 (very acid soils), 2.5 % of the plots had a pH between 7.2 to 8.5 (carbonate rich soils), and 2.5% had a pH higher than 8.5 (alkaline soils). Figure 5.8B shows that the pH had a standard deviation between 0.4 to 0.6. If an intervention is designed, and the intervention is related to a modification of the pH or a fertilizer recommendation at the municipality level, not all producers are going to have the same expected results.

The result of the ANOVA (Table 5.2) of pH per plot and the average per municipality indicates a significant difference at 99% of confidence, validating what is shown in the maps of a significant variance on the measured pH within municipalities as represented in Figure 5.8B, where it is graphically shown how different the pH is within the same municipality.

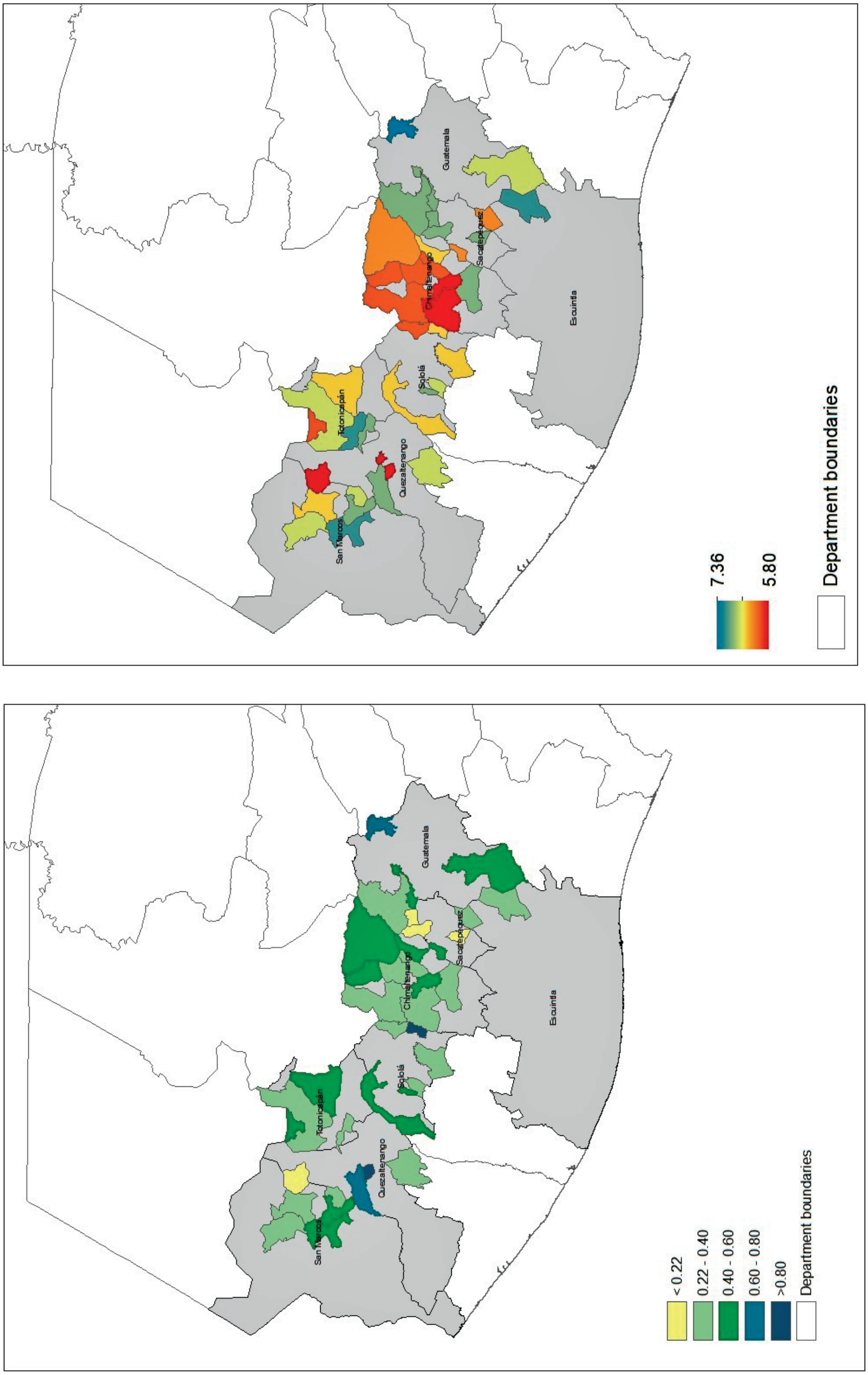


Figure 5.8: A) Soil pH by municipality in Guatemala and B) pH Standard deviation by municipality in Guatemala

Table 5.2: The variability of soil pH in municipalities in Guatemala and Honduras as described by an ANOVA

Source	Partial SS	df	MS	F	Prob>F
Guatemala					
Model	29.27	1	29.27	177.85	0.00
pH by muni	29.27	1	29.27	177.85	0.00
Residual	58.25	354	0.16		
Total	87.52	355	0.25		
	Observations	356		R-squared	0.33
	Root MSE	0.41		Adj R-squared	0.33
Honduras					
Model	160.25	1	160.25	593.23	0.00
pH by muni	160.25	1	160.25	593.23	0.00
Residual	163.96	607	0.27		
Total	324.21	608	0.53		
	Observations	609		R-squared	0.49
	Root MSE	0.52		Adj R-squared	0.49

Figures 5.9, 5.10A and 5.10B show the soil pH calculated by municipality and categorized with the official classification used in the harmonized world soil database of 2012. For Honduras, three pH classes are presented: a) very acid (4.5-5.5); b) acid to neutral (5.5-7.2); and c) carbonate rich soils (7.2-8.5). The municipality of Azacualpa in Santa Barbara department had an average pH between 5.5 to 7.2. This means that this municipality has acid to neutral soils, but 82 % of the sampling plots had a pH between 5.5 to 7.2 (acid to neutral soils), 14 % had a pH between 4.5 to 5.5 (very acid soils), and 4 % had a pH lower than 4.5 (extremely acid soils). As shown in Figure 5.10B, this municipality had a standard deviation of between 0.4 to 0.6. The municipality of Catacamas in Olancho department had a pH average of 7.2 to 8.5, but 60% of the plots had a pH between 7.2 to 8.5 (carbonate rich

soils), 37% had a higher pH between 5.5 and 7.2 (acid to neutral soils), and 3% had a pH between 4.5 to 5.5 (very acid soils). Figure 5.10B shows that the pH has a standard deviation higher than 0.8. The municipality of Danli in El Paraiso department is categorized with a pH of 5.5 to 7.2 (acid to neutral soils). However, it was found that 80% of the plot had a pH between 5.5 to 7.2 (acid to neutral soils), 17 % of the plots had a pH between 4.5 to 5.5 (very acid soils), and 3 % of the plots had a pH between 7.2 to 8.5 (carbonate rich soils), with a pH with a standard deviation between 0.6 to 0.8. If an intervention is designed, and it is related to a modification of the pH or a fertilizer recommendation at the municipality level, not all producers are going to have the same expected results.

The result of the ANOVA (Table 5.2) of pH per plot and the average per municipality show significant differences at 99% level of confidence validating what is shown in the maps of a significant variance on the measured pH within municipalities as represented in Figure 5.10B where it is graphically shown how different the pH is within the same Municipality.

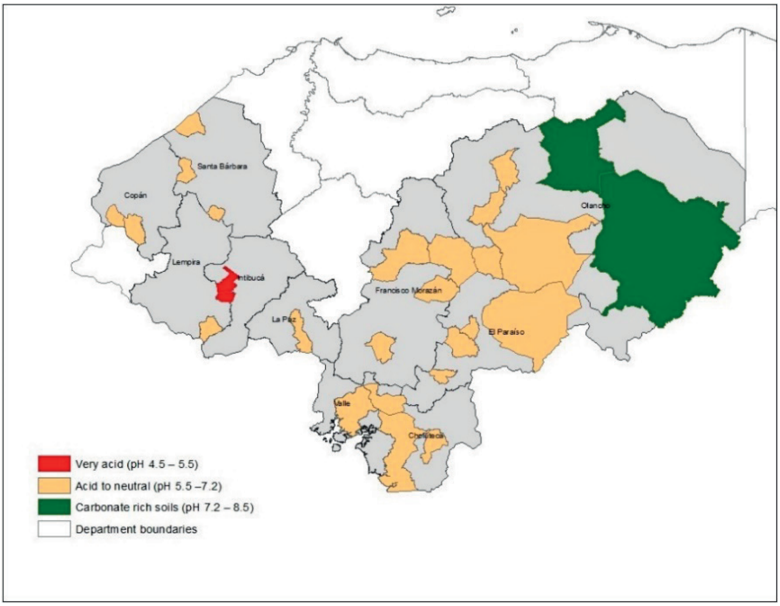


Figure 5.9: Soil pH classes by municipality in Honduras

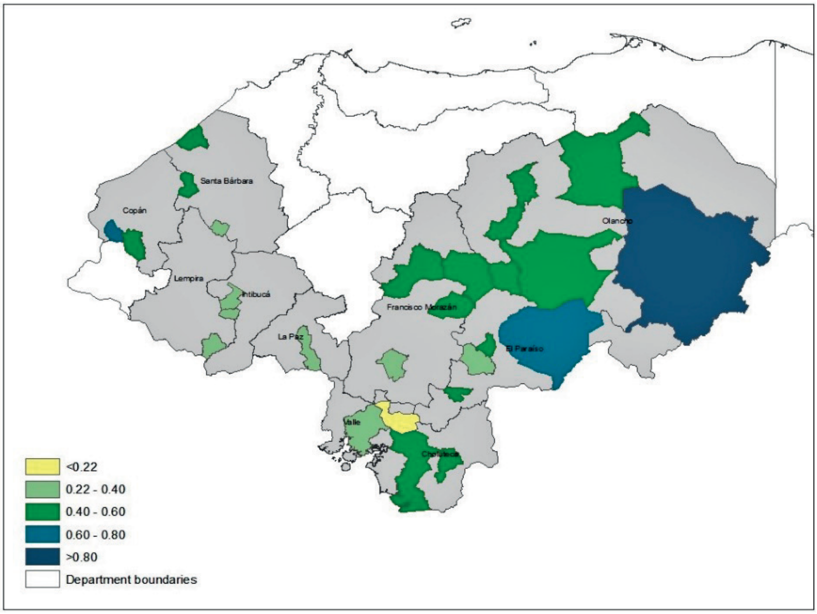
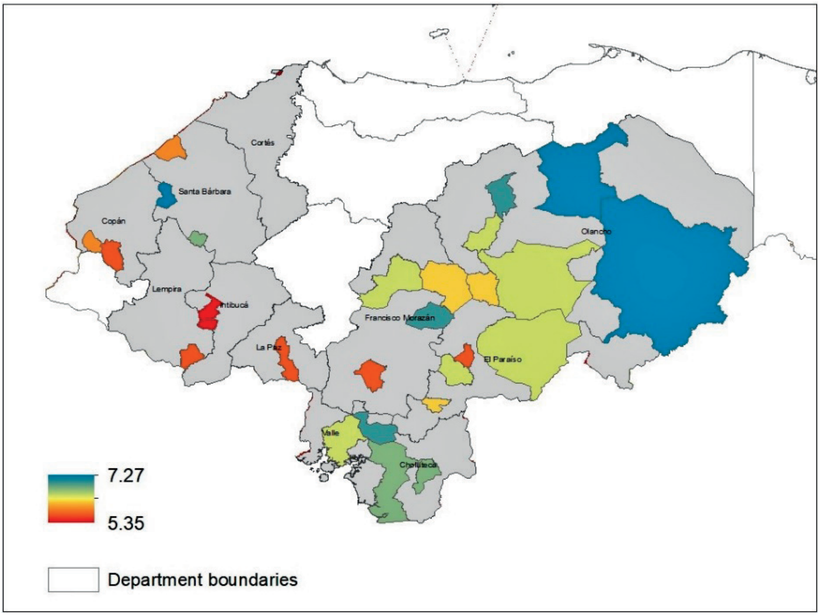


Figure 5.10: A) Soil pH by municipality in Honduras (top) and B) pH Standard deviation by municipality in Honduras (bottom)



5.4 Discussion

Technological packages implemented by governments

The technological packages are important because they improve the productivity, food security, and access to markets of the producers. However, the design of these packages needs to be a dynamic process between specialists from different fields (soil specialist, crop specialist, etc.) and producers (users). Producers generally know about the management of their crops in their particular context. In most cases, the technology used will resolve the problems faced by them (Bellon, 2001). In some cases, the knowledge of the producers on new technologies could be inadequate, but they would be willing to incorporate new information and technologies provided by extension workers and others (Bellon, 2001).

Characteristics of government packages

In Guatemala, the subsidy for the acquisition of agricultural inputs program was coordinated by the Ministry of Agriculture, Livestock and Food (MAGA). The objective was to support the subsistence populations by allowing the beneficiaries to acquire agricultural inputs to increase family agricultural production, contributing to food security. This program provided a coupon of two hundred quetzals (around US$25.00), which could be exchanged in a local store specializing agriculture. The manual of this program did not specify the products to be given out. Program information was available only for the period between 2016 and 2018.

There was little information on the criteria for receiving money provided for the technological package. It is also unclear whether the specialized local stores followed any technical criteria to recommend or distribute products — for instance, by zone or by crop. As such, it can be argued that if a producer chose the inputs and if his/her perception was correct, the producer would have chosen inputs that would have addressed the specific problems or needs he/she had. In short, the producer had the option to personalize the package.

In Honduras, the productive solidarity bonus is a program run by the Directorate of Agricultural Science and Technology (DICTA) of the Ministry of Agriculture and Livestock (SAG). This program was implemented beginning in 2010. The program provides supplies, technical assistance, training, and financing to families who produce basic food and also those who grow basic grains. The goal is to increase food security and improve the quality of life of small producers. DICTA proposed the use of appropriate technologies to increase the production and productivity of basic grains, so that surpluses can be sold in the market and raise farmers' income. The program components: (a) a solidarity voucher that provides improved seeds and fertilizers to sow a manzana of basic grains; (b) technical assistance and training provided by DICTA, in addition to the solidarity voucher; and (c) financing to incorporate technology into farming to increase production and productivity in the grain-producing sector.

The technological package was designed by the SAG at the national level. It provides improved seeds and a combination of fertilizers (NPK) for maize and beans. For beans, the package consisted of certified seed variety "Amadeus"[51] and fertilizer 12-24-12 (NPK). As the results of this study indicate, the characteristics of the soils within municipalities varied, so the impact also varied. It can be argued that a general package has met some needs of the producers, but given the variability of the soils and plots, the expected outcome was not achieved using the package's inputs.

In neither country were a farmer's perceptions and the measuring of soil pH and their variations taken into consideration into the design of the technological packages. This is disappointing, since it was clearly shown that the perception of producers must be considered; in some cases, more information should be provided to producers to reduce the knowledge/information gap they have. If a farmer does not perceive that a

[51] "*Amadeus*" is a red bean variety with a crop cycle of 73-75 days. It is resistant to the golden mosaic virus and common mosaic virus. It is moderately tolerant to rust, Anthracnose, common bacterosis, web blight, and angular leaf spot. It yields approximately 28 quintals per manzana.

problem affects him, the chances that he/she would adoption a new intervention is going to be low, and productivity will remain the same.

Table 5.3 shows the discrepancies on what the producer and the enumerator report, it also shows in the last two columns how different the interventions would have been if the producers' perceptions were taken into consideration relative to what the enumerators responded.

Suffice it to say, it is critical to involve producers in the design and implementation of the new technologies or packages. But at the same time, it is necessary that more information is provided to farmers and that the packages include technical assistance to ensure the correct use of inputs and on time.

Given the limited technical assistance, it is important to use information and communications technology (ICT) to approach more producers. New technologies must be available in local languages and with examples that make sense in the local context. Additionally, efforts should be made to use the local networks to promote new technologies and improve extension services (Banerjee et al., 2016).

Table 5.3: Difference in perceptions and potential interventions by Governments

	% of municipalities where the enumerator reports the problem at the plot level	% of municipalities where the producer reports the problem at the plot level	% of municipalities where it's recommended to do an intervention by enumerators if the municipality has more than 50% of the plots with the problem	% of municipalities where it's recommended to do an intervention by producers if the municipality have more than 50% of the plots with the problem
Guatemala				
Slope	39%	32%	43%	22%
SOM	59%	69%	43%	57%
Surface stoniness	17%	13%	11%	0%
Honduras				
Slope	31%	31%	17%	9%
SOM	29%	34%	9%	17%
Surface stoniness	19%	20%	0%	0%

5.5 Conclusions

Policymakers have questions about the use of improved technologies and the rate of adoption. A lot of research has been undertaken to find solutions to improve problems faced by the producers. Such problems relate to improving productivity (by using fertilizers, improved seeds, tools, etc.) and managing soil degradation (by using terraces, irrigation, soil organic matter, etc.). However, most of the solutions fail because they do not take into account the farmer's perceptions and the variability of the landscape. Strategies that do not consider farmers' perceptions are unlikely to be effective.

Farmers' perceptions are not simple. Not only does it refer to being aware of the existence of new technologies, but it also means understanding the real problem that needs to be resolved. For example, if a farmer perceives that his/her soil has lower pH and wants to neutralize the acid, then he can decide to use fertilizers with more aluminium sulphate and sulphur. If the farmer's perception of the problem was wrong, then he/she will not get the expected result. This will lead the farmer to reject the adoption of the inputs. On the other hand, the perception of the farmer could be correct, but the packages provided by the government, or the agro-dealers could be inappropriate to meet the farmer's needs. This will also affect the farmer's decision to adopt the package. This element of perception will increase risks and uncertainty, which explains low adoption rates (Abadi Ghadim et al., 1999; Marra et al., 2003).

The government's technological packages do not necessarily reflect the reality of the plots. Measuring the pH and electrical conductivity of soils will provide information to guide how much of the inputs should be used. For example, in Honduras the government supplied a package of fertilizer, which did not consider the levels of pH and EC of the soils. As a result, the farmers who took the risk of adopting it did not gain the expected productivity. So, the farmers' future adoption rates could be low. Another issue is that the technological packages do not incorporate the different elements that are needed to obtain the expected productivity.

Based on the results, the direct measurements (pH) and the indirect measurements (perceptions) are similar developed between bean producers in Guatemala and Honduras. However, the level of magnitude in the similarities cannot be assumed to be the same; therefore, the same technology will not have the same effect in both countries. Not only that, it cannot be assumed that a particular technology is going to have the same effect at the national level.

Concerning the technological packages, there are two scenarios to consider: (a) not all the producers are going to have the same result with the same intervention.; (b) a group of producers are going to be excluded from adopting the intervention, because the areas they are in are considered unaffected.

In summary, policymakers need to take into consideration the perceptions of farmers when developing interventions. Government policies need to respond to the reality famers face and should aim to reduce the gap in information.

Chapter 6

Synthesis

6.1 Introduction

Smallholder farms (farms of two hectares or less) have the biggest share in the number of farmers in the world (5 out of every six farms are owned by smallholder farmers), they occupy more than 12 percent of the agricultural land, with smallholders producing one third of the world's food (Lowder et al., 2021). At the same time, on average, they have very low productivity, which can be partially explained by a significant amount of food losses.

This dissertation tries to resolve this paradox of low productivity and high losses. It starts by first with an introduction (Chapter 1) and then developing a definition on food losses (Chapter 2), then continues by measuring food losses across the value chain using an innovative methodology that allows identifying quantity and quality losses and the points along the value chain in which these losses occur (Chapter 3). Food loss is quantified through three new and one more traditional measurement methodology. We follow a framework similar to de Mel et al. (2009), exploring different ways to measure food losses to identify the extent to which we can reconcile loss figures across estimation methods[52]. Chapter 4 explores the determinants of losses and possible solutions to effectively implement loss-reduction policies along every stage of the value chain.

Based upon the determinants of food losses analysis in chapter 4, the research hypothesizes that a farmer's lack of information on soil characteristics and conditions could be an important determinant of the lack of adoption and effectiveness of the technological packages and therefore affect farm productivity and increase losses across the value chain (Chapter 5). This is of core importance because preventing food losses at the local level in smallholder producers can both alleviate food shortages and increase farmers' incomes, thus improving access to food.

This synthesis assesses and discusses the conceptual framework behind the dissertation and the key hypothesis which highlights the importance of miss-

[52] In particular, we identify how far we can reconcile self-reported food losses with more detailed questions across the different stages of the value chain. In our case, the benchmark is the convergence of three alternative proposed methods.

measurement of food losses and its importance in assessing the needed policies to reduce and prevent food losses across the value chain (section 6.2.1). It also details the innovative process of data collection to be able to properly measure food losses across the value chain as well as soil characteristics (Section 6.2.2). Section 6.3 details the innovative measurement methodology and the principal reasons behind losses. The results show that contradictory to what is found in the current literature on food losses, in which it is reported that the majority of losses are mostly at the post-harvest level, the major percentage of losses occur at the producer level (60 to 80% of losses across the entire value chain) and can be mainly attributed to the pre-harvest stage and less to the post-harvest stage.

Finally, in the last section, a focus is given to soil characteristics and asymmetry in the perceptions by farmers regarding their soil characteristics and variability. When farmers' perceptions are compared to objective measurement of the soil characteristics, there are statistically significant misperceptions of soil characteristics and soil variability. This can lead to erroneous management decisions by farmers and policy makers that can affect their rate of adoption of new technologies, their productivity, and potentially the magnitude of their food losses.

6.2 Conceptual framework and research findings

Figure 6.1 shows the conceptual framework of the thesis and is used to illustrate the findings and relations between the different chapters. The proposed research is trying to understand the extent to which low productivity of smallholders could be attributed to food losses or the result of misperceptions by farmers regarding their soil characteristics and resulting management practices.

There exists significant evidence regarding low productivity of smallholders (Carter, 1984; Sial et al., 2012; Gollin, 2018; Lowder et al., 2018; Helfand et al., 2021), but there has been no detailed analysis regarding the role of loss as a driver of low productivity. FAO estimated that on average around 14% of food produced in the world is lost and the range can go even higher than 30% in developing countries (FAO, 2019). This result clearly indicates that one of the major reasons of lower productivity of smallholders could be the level of food losses they face. In addition, there is evidence showing low levels of technology adoption by smallholders (Chikowo et al., 2014, Pedzisa et al., 2015, Hermans et al., 2021) as well as in many cases policies which don't respond to the real needs of farmers are being adopted by farmers or proposed by policy makers (Chikowo et al., 2014 and Takahashi et al., 2020).

Focusing on the first component of food loses, a detailed literature review found significant inconsistencies in the definition of losses and in the measurement methodologies. Three important challenges were identified. First, there is no accurate information about the extent of the problem, especially in developing countries. For the most part, calculations of food losses hinge upon accounting exercises that use aggregate data from food balance sheets provided by national or local authorities. These "macro" estimations are subject to considerable measurement error, rely upon poor-quality data, or are not based upon representative samples. Moreover, they focus on the quantity of food lost but do not take into account potential deterioration of quality or reductions of economic value that also affect farmers and consumers. More recently, there have been efforts to use micro data to estimate food losses. These estimations rely on surveys collected among different actors across the food value chain. Nevertheless, they are based on case studies that are not representative of larger populations in a country. Additionally, these studies use different definitions of food loss, hampering comparisons across different areas and crops. Due to their lack of representativeness and differences in their methodologies, the available micro-based estimates yield inconclusive evidence about the extent of food losses.

Second, there is scarce evidence regarding the source of food losses. Food losses are associated with a wide array of factors (e.g., poor agricultural management skills and techniques, inadequate storage, deficient infrastructure, inefficient processing, lack of coordination in marketing systems, etc.) and can occur in different stages of the value chain (i.e., production, harvesting, post-production, processing, distribution, or consumption). Because of the aggregate nature of their data, macro studies are unable to identify the critical stages of significant food loss. Arguably due to the cost of primary data collection, most micro studies have not collected detailed information about the sources of food losses. Most studies aim to capture total food losses based on farmers' self-reported estimates but not to disentangle the relevant production phases in which losses are generated. For example, studies using the nationally representative Living Standard Measurement Surveys – Integrated Surveys on Agriculture (LSMS – ISA) ask farmers to assess the proportion of their crops lost to rodents, pests, insects, flooding, rotting, theft, or other reasons, and only provide global estimates. Few studies have collected more comprehensive information about particular stages in which losses occur. However, they are based on small samples in particular locations making their results difficult to extrapolate.

Third, there is little evidence of how to reduce food losses across the value chain. There have been efforts to introduce particular technologies along specific stages of the value chain (e.g., silos for grain storage, triple bagging for cowpea storage, or mechanized harvesting and cleaning equipment for wheat and maize). However, there is little evidence about adoption rates or the economic sustainability of these efforts. In particular, there is a need to better understand how to introduce economic incentives for actors from farm-to-fork, taking into account the upstream and downstream linkages across the value chain. These inconsistencies make it extremely complex to create a comparable measurement of the magnitude of losses and especially to identify where in the value chain the major losses are taking place.

With the objective of resolving these challenges, Chapter 2 of this dissertation proposes a new definition on food losses to guide measurement. Chapter 3 details an innovative methodology to measure losses across the value chain taking into account not only the loss in quantity but also in quality, as well as identifying the reasons behind these losses. This methodology also required an innovative sampling framework to be able to identify the level of losses across the value chain. Chapter 4 focuses on the determinants of losses to better understand how to reduce losses. This innovative work helped to better understand how much of the low productivity is due to food losses, i.e. the amount produced for selling is significantly lower than what was initially expected both in quantity and value, but it still does not explain the other drivers of lower productivity. Chapter 5, therefore, looks at a potentially important element behind the low productivity of smallholders, i.e., lack of technology adoption Ind i adoption of technologies that not necessarily resolved the real problems faced by smallholders. While the analysis of losses and determinants also includes technology adoption, Chapter 5 looks at the misperceptions of farmers and policy makers regarding the soil characteristics. There appears to be a significant misalignment in what farmers perceive and the reality of their soil attributes and variability. This result could help explain why there is such a low rate of adoption of relevant technology. This result affects the decisions of both farmers and policymakers, demonstrating the need for objective and scientific information on soil characteristics to reduce losses and increase productivity of smallholders.

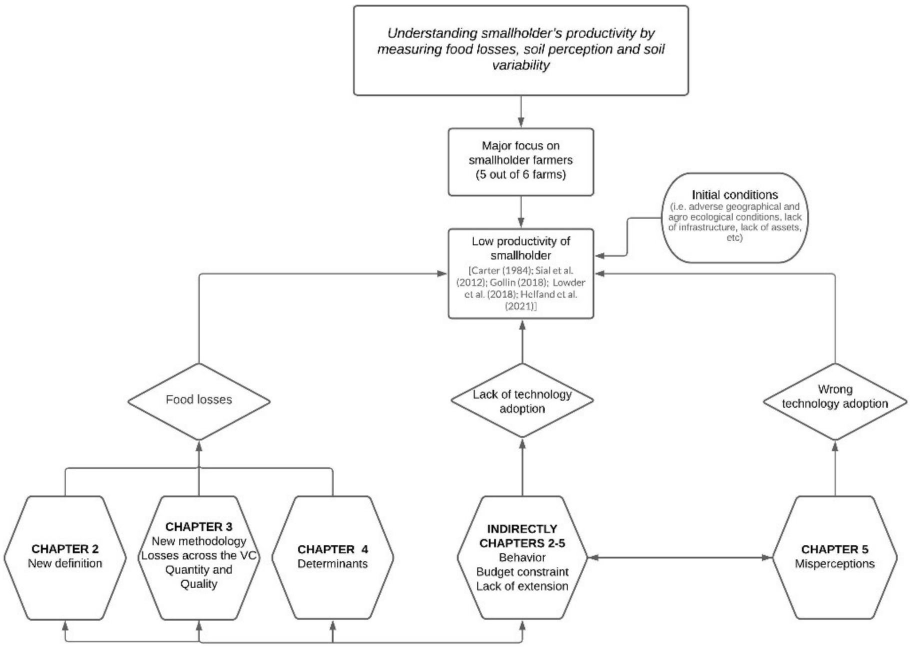


Figure 6.1: Thesis outline complemented with the main findings from each chapter

6.2.1 Key hypothesis

Our objective is to understand the concept and developed new measurement methodologies of food losses and identify the drivers of losses and low adoption of new technologies. We base this work on the following hypotheses: 1) Mismeasurement of food losses underestimate the magnitude of losses. 2) Losses are primarily at the post-harvest level and not at the pre-harvest level. 3) Lack of storage infrastructure is the main cause of post-harvest losses. 4) Farmers' perceptions reflect the real need of their soils and 5) Policymakers and farmers have similar perceptions on soil constraints.

6.2.2 Data

We have developed, implemented, and collected detail surveys across the different components of the food value chain (producer, middlemen and processor) and specific to different commodities for seven countries (Ecuador, Peru, Honduras, Guatemala, Ethiopia, China, Mozambique) and for five crops (potato, maize, beans, wheat, teff). In all of the countries studied, we sampled three nodes of the value chain (producers, intermediaries and processors). The surveyed sample was based on pre-census registration of producers who had produced the specific crop of interest in the last cropping season, which formed our baseline and applied chain-referral sampling[53] to select middlemen and processors. We adapted our instrument for the specifications of each crop and country. Using a stratified random design, we sampled a sufficient number of actors per segment of the value chain that assure statistical power in each country. For each actor, we developed detailed questions to measure quantity and quality losses which also allowed us to implement three different methodologies relative to the traditional one for comparison purposes. Table 6.1 shows the sample size of producers, middlemen, and processors in each country.

[53] Sampled farmers were asked the names of their intermediaries and processors and then a listing of intermediaries and processors was built and sample for their respective interviews.

Table 6.1: Sample Size

	Ecuador	Peru	Honduras	Guatemala	Ethiopia	China	Mozambique
Producer	302	411	1209	1155	1203	1114	774
Middlemen	182	85	325	365	---	140	203
Processor	147	139	224	245	---	53	100
Total	**631**	**594**	**1758**	**1765**	**1203**	**1307**	**1077**

Note: In the case of teff in Ethiopia, we only survey producers because most of the producers will bring their teff to millers who work on a fee-for-service basis, returning milled teff flour to the producers without any major intermediation of middlemen.

These surveys allowed us to quantify the extent of food loss across the value chain before consumption using consistent approaches that are comparable across commodities and regions, looking specifically at the production stages and the particular processes during which loss is incurred. The richness of the data allows us to provide estimates using the four methodologies and to identify the drivers and the determinants of losses.

The surveys captured detailed information about the different processes for each of these agents and quantified food losses in each of the production stages with four methodologies. More details regarding these processes are as follows:

Disaggregated self-reported measures of losses: We collected self-reported measures of volumes and values of food losses incurred during different processes (harvesting, threshing, milling, shelling, winnowing, drying, packaging, transporting, sorting, picking, transforming, etc.).

Losses based on commodity damage: We collected detailed data from farmers, middlemen, and processors on the quality (based on damage coefficients) of agricultural commodities that they use as inputs and outputs. This allowed us to quantify food losses in terms of quality attributable to each agent across the value chain.

Losses based on commodity attributes: We captured information about different types of commodity attributes (e.g., size, impurities, broken grain, etc.) and ascertained the price penalty that each of these types of crop damage entails. In this line, we were able to identify particular factors that diminish commodities' values and quantify food quality losses based on market conditions.

These surveys allowed us to quantify the extent of food losses across the value chain using consistent approaches that are comparable across commodities and regions. They also enabled us to characterize the nature of food losses and in particular, where losses are incurred across the value chain. The results of these studies will inform investments to reduce food losses.

For the producers in Guatemala and Honduras, we also developed a detailed survey and collected detail data on soil perceptions and soil characteristics (such as pH and electric conductivity) in order to explore the reasons behind low productivity and understand if there was a relationship between food losses, soils and smallholder productivity. These measurements were made in the most important plot for bean production for each smallholder for the second planting season (*postrera*) in 2017 for both countries. To do this, we used a simple empirical methodology as an approximation to identify the magnitude of the potential errors in self-evaluations or perceptions by farmers. The methodology consists of a sequential process, in which farmers are asked detailed questions, and trained enumerators then also respond to the same questions. This allows comparison between a farmer's self-evaluation of certain characteristics of their plots and the same evaluation by enumerators. Questions on perceptions were based on observable variables such as land cover, slope, and presence of organic matter, surface stoniness and texture. For this soil survey, a random sample of 450 bean producers in Guatemala and 685 bean producers in Honduras were included.

Across the different countries and commodity groups, around 90 percent of all sampled producers are male and on average, producers are 47 years old and have between 17 and 30 years of experience in growing the crops of interest. Most producers have primary education but in Peru and China, almost half of the producers also completed secondary education. Producers are rural smallholders, cultivating between 0.35 ha of land (beans in Guatemala) and 3.5 ha of land (potato in Ecuador). On average, they live 2.5 hours away from the closest village market.

Mechanization and technology adoption in production and post-harvest activities is low on average, but considerable variation exists across countries and crops. Around two thirds of all farmers use improved seeds for teff in Ethiopia and for wheat in China. However, less than 20 percent use improved seeds to grow beans and maize in Guatemala and Honduras. Resistant crop varieties are not widely common in Peru, Ecuador, and Mozambique. Machine-driven production methods, such as soil preparation, sowing, pest control, fertilizer application, weeding, mulching, cutting and harvesting, are most widely used in the Chinese wheat value chain and Peruvian potato value chain. However, they are almost non-existent in the bean value chain in Guatemala, the maize value chain in Mozambique, and the teff value chain in Ethiopia. Mechanization in post-harvest activities is even less common. Only in Honduras do farmers engage in mechanical threshing of beans and maize; very few farmers in Honduras and Guatemala mechanically dry and winnow the beans and maize. On average, producers use 2.5 different types of inputs to grow their crops (fertilizers, insecticides, herbicides, and fungicides), but there is a large variation between countries, ranging from almost no input (maize in Mozambique) to more than four different types of inputs (wheat in China).

In six out of the nine value chains, almost all producers store their grain as food reserves and seed for the next season for an average of five months (beans and maize in Guatemala and Honduras and teff in Ethiopia). About 50 percent of all wheat smallholder farmers in China and 30 percent of all potato farmers in Peru store their produce for an average of one month. Only in Ecuador, smallholders rarely store the potatoes they grow. Most smallholders (63 percent) store their produce in their house in bulk or in bags while 14 percent store them in traditional storage facilities. Less than 10 percent of sampled smallholders use metal or plastic silos, with the exception for maize farmers in Honduras. Across all countries and commodities, an average of about 50 percent of the produced crops are sold in the markets. The share is around 80 percent for the potato value chains in Ecuador and Peru, and for wheat in China. The share is considerably lower at around 30 percent in Guatemala, Honduras, Ethiopia, and Mozambique. The product is often sold directly to an intermediary on farmers' plot.

Finally, in Guatemala and Honduras, we measured the soil pH and electric conductivity and we found that in Guatemala, almost all the municipalities where soil samples were made have a pH acid to neutral (5.5 to 7.2) and had a standard deviation between 0.4 to 0.6; and in Honduras; three pH classes are presented: a) very acid (4.5-5.5); b) acid to neutral (5.5-7.2); and c) carbonate rich soils (7.2-8.5) and had a standard deviation between 0.6 to 0.8, and the electric conductivity was classified as non- saline in both countries.

6.3 Measuring food losses

Most of the literature refers to the terms 'Post-Harvest Losses' (PHL), 'Food Loss' (FL), 'Food Waste' (FW), and 'Food Loss and Waste' (FLW) interchangeably, but they hardly ever refer consistently to the same concept. For some authors, the distinction is linked to the stages at which the loss occurs. For others, the distinction is based on the cause of the food loss and whether it was intentional. Recent publications have tried to clarify this (FAO, 2014; HLPE, 2014; Lipinski et al., 2013. and FAO, 2019), by defining FL as unintentional reductions in food quantity or quality before consumption. These losses usually occur in the earlier stages of the food value chain, between production and distribution, but they also occur during the wholesale and retail stages. PHL is an element of FL and excludes losses at the production level, although losses during harvest are sometimes misleadingly included in the concept (e.g., Affognon, 2014; APHLIS, 2014). The FLW concept encompasses the totality of losses and waste along the value chain with respect to total harvested production (FAO, 2014). However, this definition does not include crops lost before harvest because of pests and diseases or crops left in the field, crops lost due to poor harvesting techniques or sharp price drops, or food that was not produced because of a lack of adequate agricultural inputs, including labor availability and fertilizer. SDG 12.3.1 basically defines losses from on farm post-harvest up to processing and packaging, including the wholesale.

To implement a strategy to reduce and prevent food loss and waste, there are three important challenges. First, there is no accurate information on the extent of the problem, especially in low- and middle-income countries. For the most part, calculations of food loss hinge upon accounting exercises that use aggregate data from food balance sheets provided by national or local authorities. These macro-approach estimates, however, are often subject to large measurement error, frequently rely on poor quality data, particularly in low- and middle-income countries, and are not based on representative samples for specific stages of the value chain. The macro-approach method is a low-cost way to obtain an indication of the overall losses along the entire value chain and was used by Gustavsson et al. (2011). The study is widely used as a reference for estimates of food loss and waste at the global level. By using the Food Balance Sheets from FAOSTAT (2019), the study estimates that around 32 percent of global food production, across all production sectors, is lost along the entire food value chain. Kummu et al. (2012) and Lipinski et al. (2013) use the same raw data and find that this translates into a 24 percent decrease in caloric terms. In country-specific studies, macro energy balances show that 48 percent of the total calories produced are lost across the whole food value chain in Switzerland (Beretta et al., 2013). Mass balance data series from the U.S. Department of Agriculture, using alternative assumptions, show that 28.7 percent of the harvested product is lost between post-production and consumption in the United States (Venkat, 2011), and that 31 percent of the available U.S. food supply is lost during distribution and consumption (Buzby et al., 2014).

More recently applied micro approaches use sample survey data regarding specific value chain actors to overcome shortcomings of the macro approach (Ambler et al., 2018; Delgado et al., 2021a; Kaminski and Christiansen, 2014; Minten et al., 2016a; Minten et al., 2016b). However, these micro approaches are costly and time-consuming to implement. In addition, it can be difficult to get a large enough proportion of responses to represent an entire value chain or region across several years. Results are also hard to compare. For example, the study by the African Postharvest Losses Information System (APHLIS) estimates that primary production and post-harvest weight loss for cereal crops in sub-Saharan Africa to be between 14.3

and 15.8 percent of total production (Hodges et al., 2014). A review of previous estimates of losses in both developing and developed countries and finds an average of 32 percent loss for fruits and vegetables (Kader, 2009).

Second, there is only scarce evidence regarding the source or causes of food loss. Because of the aggregate nature of their data, macro studies are unable to capture the critical stages at which food loss occurs. Most micro studies capture total food loss based on producers' self-reported estimates, but do not capture detailed information regarding the relative amounts of food loss incurred by different sources.

Third, there is little evidence regarding how to capture the losses effectively. There have been efforts to introduce particular technologies along specific stages of the value chain (e.g., silos for grain storage, triple bagging for cowpea storage, or mechanized harvesting and cleaning equipment for wheat and maize). However, little is known about adoption rates or the economic sustainability of these efforts, especially in low-income contexts.

The objective of this research was to improve how food loss is quantified, to characterize the nature of food loss across the value chain for different commodities in a wide array, and to disentangle the different production and post-production processes in which losses occur. We build upon the definition by FAO (2014), HLPE (2014) and Lipinski et al. (2013) and expand it by including pre-harvest losses. We include both quantitative loss and quality deteriorations in the definition of food loss. This is because from an integrated value chain perspective, pre-harvest conditions and qualitative losses have direct impacts on eventual (quantitative and qualitative) losses at later stages of the value chain due to differences in food product quality, storage and shelf-life, and transport suitability.

We quantify food loss through three new measurement methodologies and one traditional methodology. We follow a framework similar to that of De Mel et al. (2009) by exploring different ways to measure food losses to identify how far we can reconcile loss figures across estimation methods. Our goal is to identify consistency across the three proposed measures relative to the traditional aggregate measurement. Our objective is to statistically test this to argue that the proposed alternative methods provide more realistic estimates than the traditional way in which losses had been measured. To do this, the De Mel et al approach is adopted, and a benchmark is established based on observations or measured (loss) data on the farm.

For this, we designed a sampling method that allows us to have representative samples at different nodes of the pre-consumption value chain and developed a set of surveys to measure the extent of food loss using the four measurement methods in each of the specific nodes (i.e., producers, middlemen, and processors). While the surveys were tailored to specific countries, commodities, and commodity varieties, they provide a consistent measurement of food loss across different agents in the value chain. When we apply the empirical methodology to producers, middlemen, and processors in five staple food value chains in six developing countries; the comparative results suggest that losses are highest at the producer level and most product deterioration occurs before harvest. Aggregated self-reported measures, which have been frequently used in the literature, consistently underestimate actual food loss.

Proposed empirical approach

By drawing on the literature and economic theory, we developed and implemented three alternative methodologies, in addition to the traditionally used methodology of aggregate self-reported measures of loss. All four methodologies can measure losses at different stages of the value chain and can be applied across crops and regions.

All methodologies estimate both the total food that is lost (quantity degradation, estimated in quantity or value) and the product that, albeit not being completely lost, is affected by quality deterioration (estimated in quantity or value). At the producer level, we estimate losses from harvest to post-harvest sale, while the reference period is the last cropping season. For the middlemen and the processors, we estimate losses from purchase to sale, during a defined time period (depending on the country). Due to the heterogeneity of the crop transformation processes at later stages in the value chain, at the processor level, only the aggregate self-reported measurement method may be used. The four methodologies are described below and Tables 6.1 and 6.2 provide the specifications.

Aggregate self-reported method

The “aggregate self-reported method” (S-method) is based on reporting by the producers, middlemen, and processors regarding the food losses they each incurred. Self-reporting of loss figures has been widely used in recent studies on food loss (e.g., Ambler et al., 2018, Kaminski and Christiansen, 2014; Minten et al., 2016a; Minten et al., 2016b).

Category method

The “category method” (C-method) is based on the evaluation of a crop and the classification of that crop into quality categories. The method builds on the “Visual Scale Method,” developed by Compton and Sherington (1999), to rapidly estimate quantity and quality grain loss. The C-method classifies each product into its end use (i.e., suitable for export, the formal market, the informal market, animal feed, etc.). Each category is associated with a crop damage coefficient, a percentage between 0 and 100 representing the share of the product that is damaged from each category.

Attribute method

The “attribute method” (A-method) is based on the evaluation of a crop according to inferior visual, tactile, and olfactory product characteristics. At the time of the survey, the producer evaluates his or her production and establishes the share of total production that is affected by the inferior damage attributes, both after production and after post-harvest. Middlemen evaluate their product from the previous month at both purchase and sale. The producer and the middlemen declare how much their respective buyers discount prices paid as a result of inferior product attributes. This information is used to estimate the value loss.

Price method

The "price method" (P-method) is based on the reasoning that higher (or lower) values of a commodity reflect higher (or lower) quality. A decrease in price, all else equal, is thus a proxy for a deterioration in quality. Data regarding producers' and middlemen's ideal sale value are used and compared to the value of their actual production, purchase, and sale.

Variables and formulas at the producer level

As detailed in Table 6.2, at the producer level, $WeightLoss_p$ is the physical quantity that disappears for producer *p* between harvest and post-harvest (quantity degradation) plus the post-harvest loss in each category based on an industry-defined rating of crop damage by category (quality degradation). $ValueLoss_p$ is the value of the physical quantity that disappears between harvest and post-harvest (quantity degradation) plus an industry-defined price punishment by category (quality degradation).

Variables to calculate weight loss at the producer level

$Q_{Prod,p}$ and $Q_{PH,p}$ are respectively the total quantity of all production (and the level at post-harvest) from producer *p* , as indicated by the producer. Ci is the damage coefficient for category *i* (where the total number of categories are *I*), $QC_{iPH,p}$ is the quantity in each category after post-harvest, and $a_{j,p}$ is the share of product affected by damage attribute *j*.

Table 6.2: Formulas used to calculate weight and value losses at the producer level for the 3 new methodologies

	Weight loss	Value loss
Category	$(Q_{Prod,p} - Q_{PH,p}) + \sum_{i=1}^{I}(C_i * QC_{iPH,p})$	$(V_{Prod,p} - V_{PH,p}) + \sum_{i=1}^{I}(\bar{P}_{ideal,p} - \bar{P}_{Ci,p}) * QC_{iPH,p}$
Attribute	$(Q_{Prod,p} - Q_{PH,p}) + \sum_{j=1}^{J} a_{j,p} * Q_{PH,p}$	$(V_{Prod,p} - V_{PH,p}) + \sum_{j=1}^{J} \overline{Pa}_{j,p} * Q_{PH,p}$
Prices	$V_{ideal,p} - V_{PH,p}$	$\frac{ValueLoss_p}{\bar{P}_{ideal,p}}$

Variables to calculate value loss at the producer level

$V_{Prod,p}$ and $V_{PH,p}$ are respectively the value of production and value of post-harvest production as given by the multiplication of respectively $Q_{Prod,p}$ and $Q_{PH,p}$ by an ideal price $\bar{P}_{ideal,p}$. $\bar{P}_{ideal,p}$ is the average sale price for an ideal product and $\bar{P}_{Ci,p}$ is the sample average sale price for a product in category *i*. $\overline{Pa}_{j,p}$, is the average price punishment for an inferior product attribute at sale. $V_{ideal,p}$ is the ideal value of a producers' production and is obtained by multiplying producers' production by the average ideal sale price. $V_{PH,p}$ is the total value of the producers' production after harvest, as assessed by the farmer himself.

Variables and formulas at the middlemen level

At the middleman level, as detailed in Table 6.3, the quantity and quality degradation in weight ($WeightLoss_m$) and in value ($ValueLoss_m$) for middlemen *m* is calculated using the formulas detailed in the table.

Specifically, when looking into weight loss at the intermediary level, i.e. column 1 of Table 6.3, *Ci* is the same damage coefficient as in the producers' survey, and $QC_{iSale,m}$ and $QC_{iPurchase,m}$ are the quantities in each category at purchase and at sale. $WeightTotLost_m$or $ValueTotLost_m$, i.e., product that completely disappeared from the value chain. $Q_{Purchase,aj,m}$ and

$Q_{Sale,aj,m}$ are the quantities in each attribute sold and purchased with a certain damage attribute by middleman *m.*

Similarly, when looking at the variables needed to calculate value loss at the middlemen level, i.e. column 2 of Table 6.3, $\bar{P}_{ideal,m}$ and $\bar{P}_{Ci,m}$ are the average sale price for an ideal product and sale price for a product in category *i* at the middlemen level. $V_{Purchase,aj,m}$ and $V_{Sale,aj,m}$ are the values at sales and purchase that are lost due to a damage attribute.

The comparison with the subjective method is in the sense that traditionally in previous work farmers are asked directly about the magnitude of the aggregate losses. In these new methodologies all elements of losses are decomposes to better measure it. While the farmers provide the responses, the questionnaires were developed with enough disaggregation through a series of questions that allows to minimize the measurement error relative to an aggregate gross response of the total number of losses. Moreover, the use of three different methods allow us to compare how accurate these three methods are by looking at their consistency relative to the self-reported estimates.

Table 6.3: Formulas used to calculate weight and value losses at the middlemen level for the 3 new methodologies

	Weight loss	Value loss
Category	$WeightTotLoss_m + \sum_{i=1}^{I} C_i * (QC_{iPurchase,m} - QC_{iSale,m})$	$ValueTotLoss_m + \sum_{i=1}^{I} (\bar{P}_{ideal,m} - \bar{P}_{Ci,m}) * (QC_{iPurchase,m} - QC_{iSale,m})$
Attribute	$WeightTotLoss_m + \sum_{aj=1}^{J} (Q_{Purchase,aj,m} - Q_{Sale,aj,m})$	$ValueTotLoss_m + \sum_{aj=1}^{J} (V_{Purchase,aj,m} - V_{Sale,aj,m})$
Prices	$(Q_{Sale;ideal,m} - Q_{Sale;actual,m}) - (Q_{Purchase;ideal,m} - Q_{Purchase;actual,m}) + WeightTotLoss_m$	$(V_{Sale;ideal,m} - V_{Sale;actual,m}) - (V_{Purchase;ideal,m} - V_{Purchase;actual,m}) + ValueTotLoss_m$

6.3.1 Results

Figure 6.2 shows loss levels at the producer, middlemen, and processor levels separately and alternatively for the four estimation methodologies (i.e., aggregated self-reported (S), category (C), attributes (A), and price method (P)). Loss figures include both the quantitative degradation (i.e., product that completely disappeared from the value chain) and the quality degradation (i.e., the product affected by quality deterioration).

As shown in Figure 6.2a and 6.2b, loss figures across all value chains fluctuate between 6 and 25 percent of the total production and total value of production. Loss figures are consistently largest at the producer level and smallest at the middleman level. Across the different estimation methodologies, loss at the producer level represents between 60 and 80 percent of the total value chain loss, while the average loss at the middleman and processor levels is around 7 and 19 percent, respectively. At the processor level, losses fluctuate between 2 and 3 percent.

Percentage losses expressed in value tend to be slightly smaller than those expressed in weight for the S-method. This difference is prominent in the A-method, indicating that the market does not seem to penalize some quality degradation at the farm level. The category method leads to results that are more similar in terms of weight and value loss.

Losses at the producer level can be mainly attributed to the pre-harvest stage (on average 4.13 percent of the total production volume and 4.19 percent of the total production value) and less to the post-harvest stage (on average 8.30 percent of the total production volume and 6.82 percent of the total production value) or quantities left in the field (less than 1 percent). The S-methods systematically report lower loss figures than the C-, A-, and P-methods across both the pre- and post-harvest stages at the producer level.

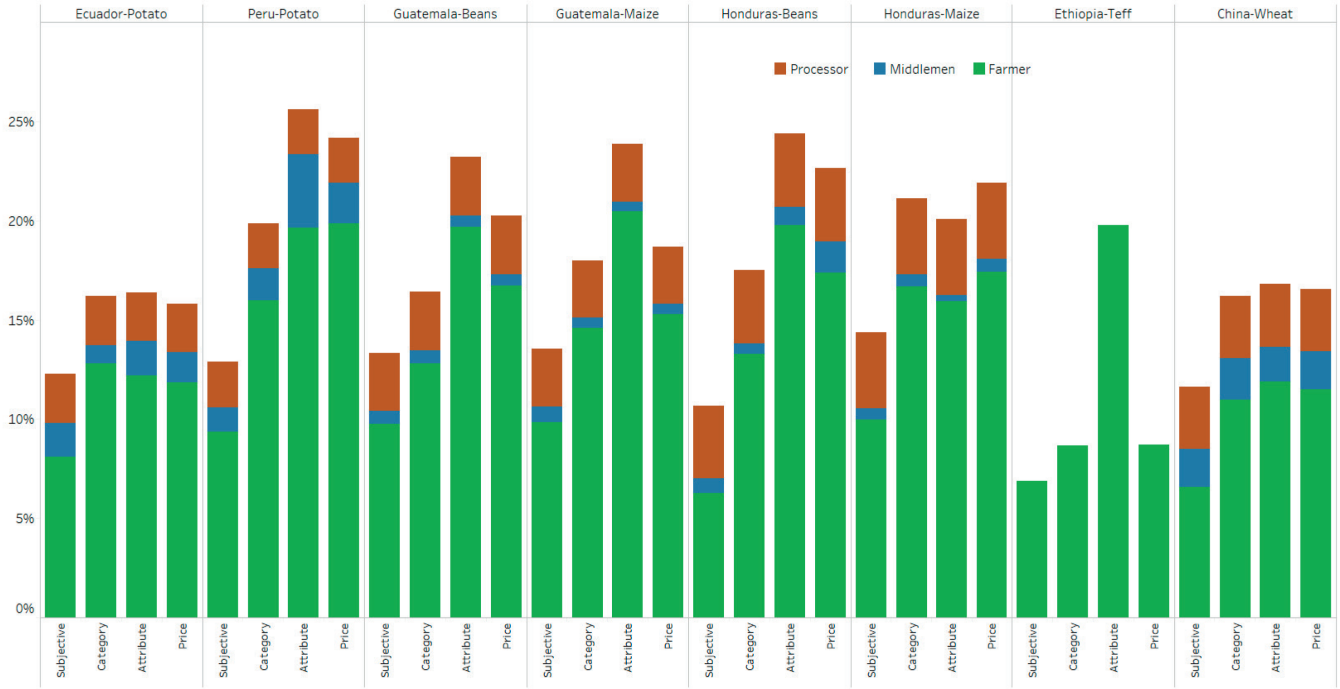
Differences across methodologies are salient, especially at the producer level. While the estimation results from the three new methods implemented (category, attributes and price) are similar with differences that are mostly not statistically significant, the aggregate self-reported method reports systematically lower loss figures. Therefore, in the future, it is expected that using one of these methods will be sufficient and given its ease of use, the attribute method is likely to be the easiest.

6.3.2 Causes of food losses

Figure 6.3 presents the major reasons producers cited for their pre-harvest loss, non-harvested crop, and their post-harvest loss. In the specific case of pre-harvest loss, the major reasons reported by producers included pests and diseases and lack of rainfall; teff was the exception, with lack of rainfall being the major reason reported for pre-harvest loss. When looking at the non-harvested crop, the major reason for the loss is a lack of appropriate harvesting techniques. Potatoes in Ecuador was the exception, with small or poor-quality potatoes being the major reason reported for produce left in the field. Both in Ecuador and Peru, worker shortages or excessive labor costs are important limiting factors. In China, weather conditions are one of the main reasons why produce is not harvested. The main causes of post-harvest losses, with the exception of China and Ethiopia, are damage to crops done by workers during harvesting or sorting, because of their lack of training and experience.[54] In China, mechanical damage is most prevalent, followed by damage caused by laborers during harvesting. In Ethiopia, most post-harvest losses occur because produce is blown away or spilled, or due to poor storage and damage by laborers.

It is important to mention that causes such as cost of labor or low market price are endogenous to the specific commodity and market structure location. Therefore, this needs to be taken into consideration when interpreting and comparing the results across commodities and countries.

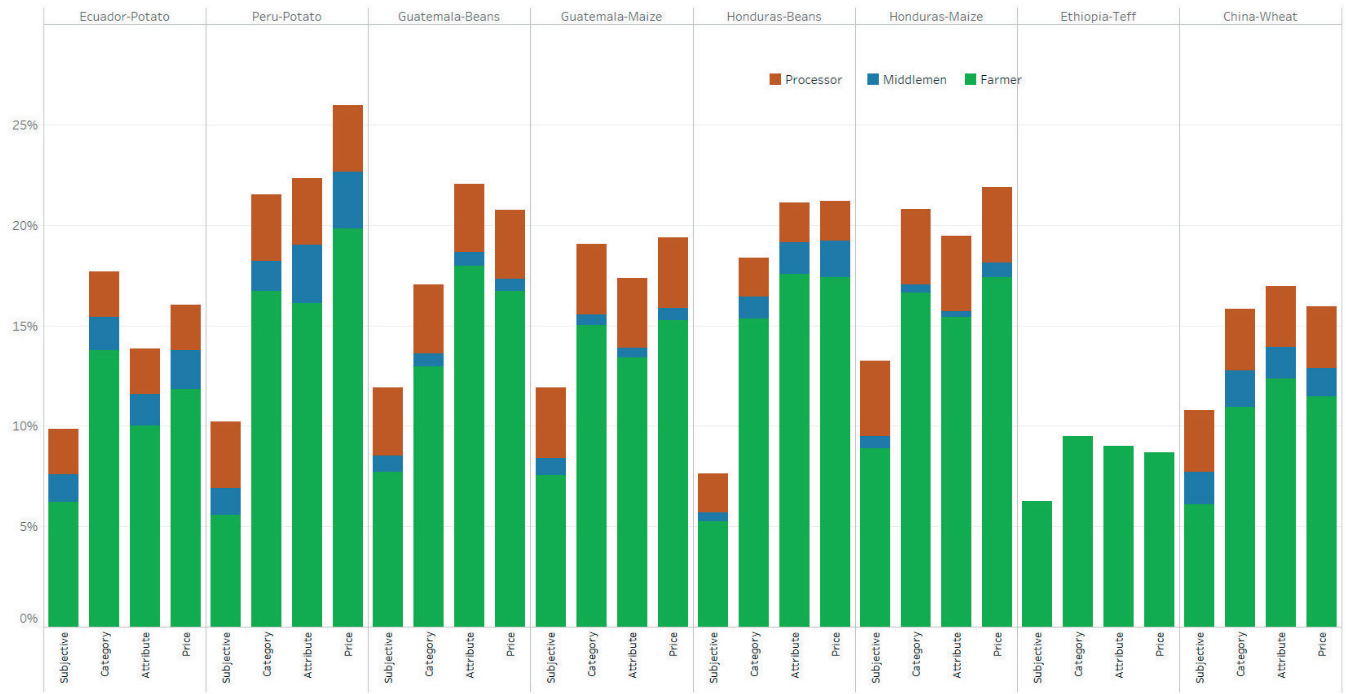
[54] For further details on determinants of food losses, see Delgado et al. (2021a).



a) Food Loss in Percentage of Total Production (Volume)

Figure 6.2: Quantitative and Qualitative Food Loss along the Value Chain, Estimated Using Four Methodologies

^For teff in Ethiopia, data covered the producer chain only, given that there are no important middlemen and processors in this value chain.



b) Food Loss in Percentage of Total Value of Production (USD)

Figure 6.2: Quantitative and Qualitative Food Loss along the Value Chain, Estimated Using Four Methodologies

^For teff in Ethiopia, data covered the producer chain only, given that there are no important middlemen and processors in this value chain.

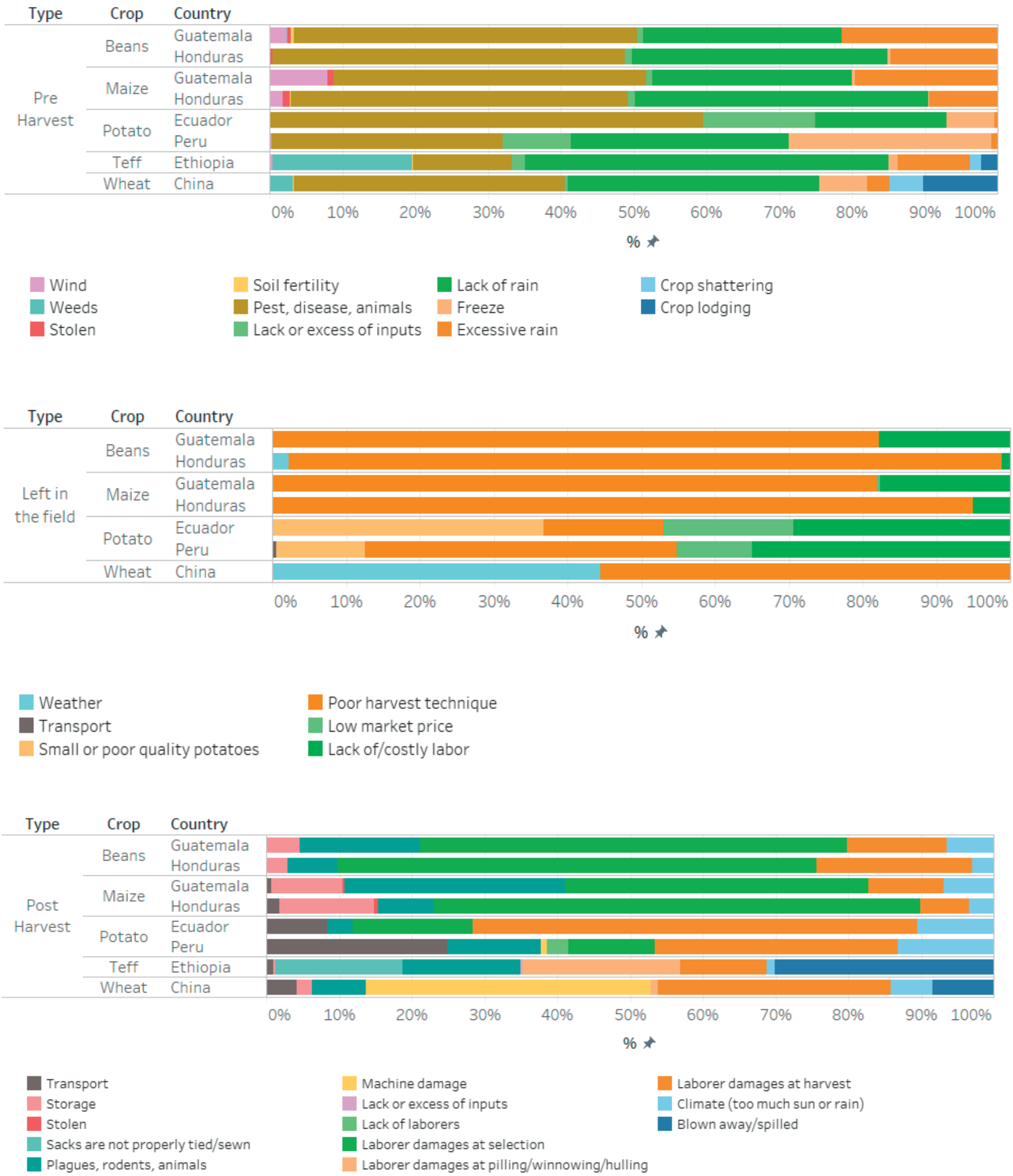


Figure 6.3: Self-Reported Causes of Losses

6.4 Identify key determinants of losses across the value chain

As mentioned, food loss (FL) can occur at different nodes of the value chain: production, harvest, or post-harvest stages, involving storage, transport, handling, or processing. In chapter 3, we use a statistical framework to assess the association between different socio-economic and production factors and food loss at the producer level. Methodologically, we use two alternative econometric models: the model of classical maximum likelihood estimation is used to assess the relationship between the right-hand side variables and the binary FL variable; fractional response generalized linear models (GLM) are used on the share of product loss to account for the boundedness of the dependent variable. We use these models to estimate the relationship among these variables, using food loss data. Food loss is defined through the "attributes method" (see details in Delgado et al., 2021a).

With this in mind, our main goal was to determine the correlation between producer FL and socio-economic characteristics, market access, agricultural production techniques, on-farm post-harvest practices and climatic and geographic variables (e.g., weather, pests, etc.). Given the uncertainties on the origins of loss, we believe that the intensity of correlations can provide insight into the causal effectiveness of targeted interventions for future studies.

We classified the potential origins of food loss in five groups: socio-economic characteristics of the farmer; market access; mechanization and technology; storage facilities; and growing conditions (pests and disease); and climatic conditions. Overall, we notice that there is a considerable heterogeneity in the determinants of food loss across commodity and country contexts.

Socio-economic characteristics. Most farmers are men, but there is no clear gender pattern in food loss across countries and commodities. Age, education, and experience tend to be negatively correlated with the probability and share of food losses. The number of years in which a producer has been producing a specific crop significantly correlates with the reduction in losses in the potato value chain in Ecuador, the bean and maize value chain in Guatemala, and the maize value chain in Mozambique. In addition, we find that in Peru and Ecuador when a producer's main income[55] stems from an agricultural activity, it is correlated with lower losses and this difference is statistically significant. This result is in line with the outcome we find on crop cultivation experience.

The costs or time to reach markets have a significant correlation with increased losses in five of the seven countries. In Peru, Guatemala, Mozambique, Ethiopia, and China, the absence of markets can represent important limitations for farmers. Farmers in these countries decide not to market (or even harvest) all produce because of the high costs relative to the market price. Mechanical transport with a car is associated with a significant increase of these costs through additional losses during travel in beans and maize value chains in Guatemala. The farmers in our survey mention lack of access to markets and credits as a challenge to increasing production of high-quality products.

Surprisingly, mechanization and technology in production and post-harvest activities have negative correlations with loss across value chains and countries, highlighting the importance of adequate knowledge. On the other hand, the number of machine-driven activities correlates with increased losses in the Ecuadorian potato value chain, Guatemalan maize value chain and Chinese wheat value chain.

The mechanization of harvesting tools considerably affects losses, and the use of resistant varieties or Improved seeds have a consistent correlation with reduction of losses. Unfortunately, mechanical post-harvest activities are not widespread, with mechanical drying, winnowing, and threshing activities being observed only in the maize and bean value chains in Honduras and Guatemala. Increased mechanization in the drying and winnowing activities reduces loss in the bean value chain in Guatemala and the maize value chain in Honduras but mechanical threshing increases losses in the bean value chain in Honduras and the maize value chain in Guatemala. Farmers likely incur grain damage, cracks, and lesions when mechanically

[55] We have the farmers' income data only for Peru and Ecuador.

(instead of manually) stripping the grain from the plant. This makes the grain more vulnerable to insects and visually less appealing.

Most of the harvesting is still performed manually in these countries, making it labor intensive and slow. During the harvest season, countries may face labor shortages, which can be resolved by hiring external labor which is correlated with reduction of losses.

A lack of adequate storage techniques can lead to food loss due to biotic factors (pest, insects, fungi, and rodents), abiotic factors (rain, temperature, humidity), or spillage when filling or emptying storage space. Post-harvest storage is correlated with increased loss in the bean value chains in Guatemala and Honduras, the maize value chain in Mozambique, and the wheat value chain in China. In Honduras and China, the storage duration is correlated with increased production loss. Storage conservation activities, such as chemical or natural fumigation, or increased ventilation, are correlated with reduced losses in Honduras and Ethiopia.

Unfavourable climatic conditions, pests, and diseases are often mentioned as problems farmers face during production. In Honduras, Guatemala, Mozambique, and Ethiopia, unfavourable climatic conditions, as assessed by farmers, are positively correlated with the likelihood of incurring losses and the share lost. Therefore, is important to take into account how to manage the practices especially during pre-harvest to reduce the effects of this problems as is using improved seeds, insecticides and soil conservation practices to reduce the effect of unfavourable climatic conditions.

Some soil characteristics (like pH, moisture, nutrients organic matter, etc.) are relatively easy to modify to favor plant health, reduce the presence of weeds and increase yields. For example, "Some diseases strongly depend on the levels of some yield-limiting factors (or their alleviation). For instance, brown spot of rice, caused by the fungus *Cochliobolus myabeanus*, is dependent on the occurrence of drought (Chakrabarti 2001), or yield losses caused by Septoria diseases of wheat depend on cropping practices, especially fertilizer inputs (Leath et al., 1993).

6.5 Soil characteristics and conditions as a determinant of losses

The analysis of losses and determinants partially also included an understanding of lack of technology adoption but we want to determine if this is due to misperceptions by farmers and policy makers of the actual needs given the soil characteristics of the farmers. We would hypothesize that farmers' lack of information on soil characteristics and conditions could be an important determinant of the lack of adoption and effectiveness of the technological packages and therefore affect farm productivity and increase losses across the value chain. In chapter 4, we measure the asymmetry on the perceptions by farmers of their soil characteristics and the variance of soil pH between plots and found significant misperceptions of soil characteristics and misunderstanding of the real constraints. To accomplish this objective, we evaluate in an ex-ante manner whether these factors can play a role in low the adoption of interventions. In this chapter, the difference in perception between the farmer and a proxy to the scientist (i.e., trained enumerator) for the environmental characteristics including soils are studied.

The literature is clear in that there is a general problem of low adoption of technological interventions in agriculture (Hermans et al., 2021). The low adoption rate has been widely studied in the literature and different reasons have been identified and these includes the following: a) farmer characteristics (i.e. age, training, and social capital); b) plot characteristics (i.e. quality of the land matter; sloped); c) behavioural characteristics of the farmers (i.e. their level of risk aversion, intertemporal discount rates, and time preferences); d) access to markets and to capital and credit; e) distance to innovators or social networks; f) economic decisions made by the farmer of the allocation of their limited resources (i.e. If a farmer owns more than one field, he or she may not invest equally in each field, because of their limited natural, human, and economic capital); and g) access to information and extension services.

All of the previous reasons that explain adoption are more focused on existing assets (human capital and land), on access to resources but economic and social (networks, credit, markets, characteristics of the plot, and supply of extension services), and on behavioural issues (rate of risk aversion and intertemporal discount rates) but they fail to identify the most appropriate technological intervention. It is important to consider that the low adoption rate is related with some characteristics of the producers but also because the technologies proposed are not targeted to the producer or constraints on the plot.

To better evaluate the disconnect between soil needs and farmers' perceptions, a simple empirical methodology was proposed as an approximation to identify the level of magnitude of the potential errors in self-evaluations or perceptions by farmers of Guatemala and Honduras. The methodology consists of a sequential process in which detailed questions are asked to farmers and the same questions are then responded by trained enumerators so as to be able to compare the difference between a farmer's self-evaluation of certain characteristics of their plots and the same evaluation standardized through trained enumerators. All the questions on perceptions were based on observable variables like land cover, slope, and presence of organic matter, surface stoniness and texture. The producers were asked questions about characteristics of their agricultural plots and about land management and the characteristics of the agricultural plots were also assessed by the enumerators.

For land cover, the perception of enumerators and producers is similar for both countries between enumerators and producers in bare soil and cropland, and for Honduras in shrubland. Major differences in perception are with the option shrubland in Guatemala. The producers see more bare soil than the enumerators, also in the plots where the enumerators see crops in Guatemala. For slope, a huge variance (difference) in the perception between enumerators and producers is shown and the producers see their plot with a lower slope in both countries. Regarding organic matter, in both countries, the producers underestimate the presence of organic matter in their plots. Regarding surface stoniness, not much difference in perception is seen, but the perception of the presence of stones is lower in the producer side in both countries.

When a comparison was done between perception of the enumerator on the organic matter content and the producer perception on the fertility of each plot, 90 percent of the producers consider their plot fertile. Because of the variation of the results, it seems the perception of fertility of the plots is not only related with the presence of organic matter. The producers could be related the fertility more with yields.

We also compared the abundance of materials (sand, silt, and clay) in the soil by the enumerators and the perception of the producers. For the main soil component in Honduras, the predominant materials were identified as sand and silt both for enumerators and producers while in Guatemala, with the presence of the three materials well distributed, with more differences in perception in Guatemala. In the case of the second most dominant soil component, we found more differences between enumerators and producers in both countries.

When we measured the soil pH, we found a significant variability within municipalities for both countries; this information is important for designing interventions. For example, Figure 6.4 shows how different the interventions would have been if the producers' perceptions were taken into consideration relative to what the enumerators responded.

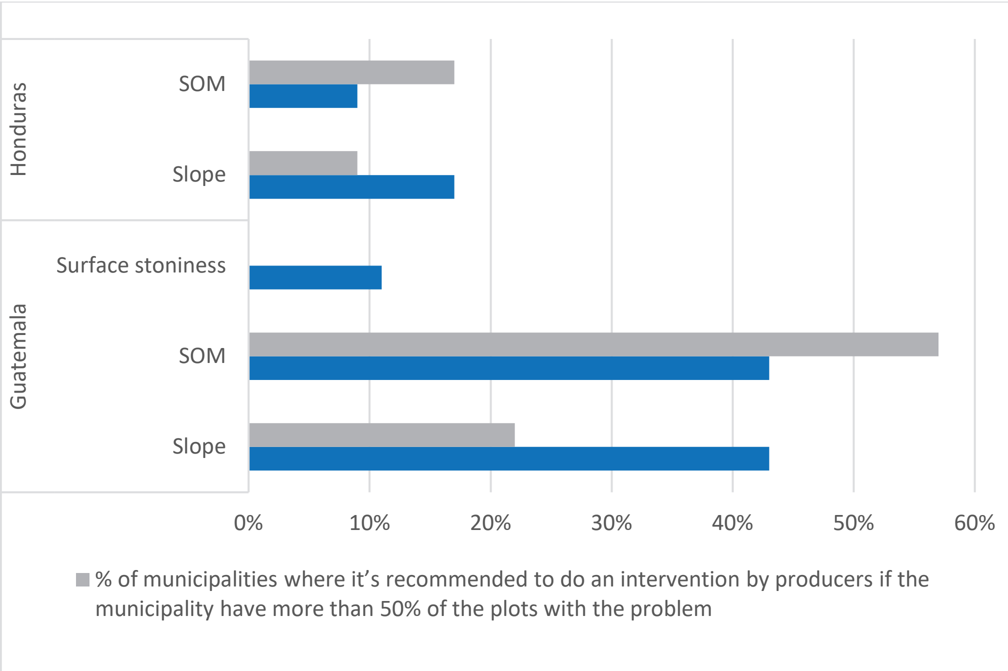


Figure 6.4: Difference in perceptions and potential interventions by Governments. Source: Authors' elaboration

Note: Surface stoniness in Honduras was 0% for both variables.

Is in this respect that improving the information to farmers of their soil characteristics is a necessary condition to accelerate the adoption and effectiveness of the technological packages (i.e., fertilizers and seeds). In addition, reducing the asymmetry of information of policymakers relative to the real constraints of farmers will also contribute to the efficiency and effectiveness of their policies aimed at increasing productivity.

6.6 Policy Implications of research findings

6.6.1 Importance of magnitudes of losses across the value chain to better target policies

Identifying the magnitude, causes, and costs of food loss and waste across the value chain is critical for setting priorities for action. Addressing food loss across the value chain first requires a common understanding of the concept by all actors, as well as a collaborative effort to collect better micro data across different commodities and contexts. This will help to better target interventions and to identify the needed technologies, value chain infrastructure, and extension services to minimize losses. Most of the losses faced at post-harvest, has been generated at pre-harvest, i.e., aspergillus flavus (the fungus who generated aflatoxins), contaminated maize in the field; high aflatoxin contamination is commonly associated with high stress for plant and fungi mainly caused by high temperature and drought (Moreno and Kang, 1999).

Policymakers and value chain actors need to translate these insights into action. International organizations have the power to highlight the importance of food loss reductions and create platforms for information exchange; at the same time, individual states play a key role in creating a successful enabling environment. All public and private value chain actors need to work together to transform theory into interventions to reduce food loss and waste.

6.6.2 Alternative solutions of determinants of food losses

While there are commonalities, food loss is very context specific. The heterogeneity suggests that policies aiming at the reduction and prevention of food loss need to be developed with specific commodities and contexts in mind. For example, being a male farmer tends to be correlated with 4.9% to 10.9%reduction of beans loss, but it is associated with, respectively, about 10% points more likelihood to incur in a loss of maize and 5% more points share of maize loss in Guatemala and Honduras (Delgado et al., 2021b).

Governments should ensure that public and private sector investments facilitate reductions in food losses by identifying the main causes of food loss in specific commodities and contexts. Such investments cover a broad gamut of areas related to food systems, including food safety, education, and infrastructure, regulations and standards, and market failures.

Smallholders, who produce only small surpluses, often face substantial market failures that contribute to food loss. Public sector investment can address some of these shortcomings, such as the need for appropriate storage facilities, efficient transport systems, policies that improve access to credit, support for market incentives for improved food safety as in the case of aflatoxins, and access to crop varieties resistant to weather shocks. Reducing food loss can generate profits.

6.6.3 Reducing asymmetry of information to improve effectiveness of technological packages and adoption of soil practices

Understanding how farmers perceive their soils and comparing this to actual soil characteristics will help design more targeted policies to improve soil quality increasing productivity and efficiency in the use of inputs. Policy makers need to take into consideration the perception of farmers and their packages and policies need to respond to the reality faced by the farmers and should also aim to reduce the asymmetry of information faced by some producers. This will help facilitate the harvest of better-quality crops and reduce losses.

6.7 Conclusions

Feeding a growing population in a sustainable way is a big challenge (Cui et al., 2018), and this is even more of a challenge in places where smallholders are predominated. Smallholders face different constraints like weak infrastructure, environmental problems, lack of technical expertise, soil fertility, etc. that decrease their productivity (Raimi et al., 2017).

Addressing food loss across the value chain requires a common understanding of the concept by all actors. A collaborative effort is also required to collect better micro data across the value chain and across different commodities and contexts. We address this existing measurement gap by developing and testing three new methodologies that aim to reduce measurement error and assess the magnitude, causes and costs of food loss, as well as the stage across the value chain where losses occur. The estimation results from the three new methods are similar with respect to the aggregate self-reported method, which shows systematically lower loss figures. Loss figures are consistently largest at the producer level and smallest at the middleman level. Across the different estimation methodologies, loss at the producer level represents between 60 and 80 percent of the total value chain loss, while the average loss at the middleman and processor levels is at around 7 and 19 percent, respectively.

Identifying the causes and costs of food loss across the value chain is critical for setting priorities for action. Analysing the factors affecting food loss at the micro-, meso-, and macro-levels can help to identify effective reduction interventions. Our results show that socio-economic characteristics, such as education and experience, positively correlate with the reduction of losses. In four out of the nine value chains studied, the association of education and the number of years a producer has grown specific crops with reduction of losses is significant. Unfavourable climatic conditions are positively correlated with losses in most countries; and major production problems mentioned by farmers are pest, diseases, and rodents. The techniques that constitute proper handling of produce may vary from case to case. The number of inputs applied follow similar mixed trends. This emphasizes the critical need for knowledge and training in addition to adopting technology to effectively decrease losses. The lack of appropriate storage techniques is consistently correlated with higher losses and longer storage durations tend to exacerbate the losses. Improved storage infrastructure can mitigate these risks. The cost of accessing markets also is significantly correlated with increased losses. This indicates that the absence of markets represents critical limitations for farmers.

Preventing food losses at the local level in smallholder production can both alleviate food shortages and increase farmers' incomes, thus improving access to food. The perception and understanding of the constraints will be central to increasing adoption rates for new technology or practices. Identifying the problem, and bringing information to the farmer and policy makers such that his (her) perception is as close as possible to the actual constraints (for example, regarding soils), will affect several of the elements mentioned as determinants of adoption.

More research is needed to identify the drivers behind losses. For example, disentangling the role of farmers' demography, education, producer experience, and gender is needed. It is necessary to analyse the factors related to production — access to technology and agricultural assets, infrastructure — geography and climate. Furthermore, experimental studies on different storage techniques and mechanizations, and targeted training programs can confirm the effectiveness of specific interventions on food loss reduction.

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Summary

Agri-food systems must be transformed to provide enough quantity of healthy food for everyone in a sustainable way, including those involved in the production chain, while dealing with the dynamics of local and global economies and the environment. Transforming the agri-food systems requires a combination of research, policies, and investments to manage complex trade-offs.

Food loss and food waste have become an increasingly important topic in the development community and in the transformation of the agri-food systems. Food losses represent 14% of the global production, according to FAO, 2019. This is equivalent to $400 billion annually. In fact, the United Nations included the issue of food loss and waste in the Sustainable Development Goal target 12.3, which aims to “halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” by 2030.

Growing populations and changing diets associated with greater wealth are increasing the pressure on the world’s available land, constituting serious threats to food security. Policies to reverse this situation have aimed mainly at increasing agricultural yields and productivity, but these efforts are often cost- and time-intensive. Greenhouse gas emissions linked with food losses are equivalent to about 1.5 gigatonnes of CO_2. In addition, food loss entails excessive use of scarce resources. For example, each year 75 billion of cubic meters of water is used to produce fruits and vegetables that are not eaten. Finally, the loss of marketable food can reduce producers’ income and increase consumers’ expenses, likely having larger impacts on disadvantaged segments of the population. The losses of fruit and vegetables are equivalent to 912 trillion kilocalories and micronutrients. This is happening, as 3 billion people do not have access to healthy diets.

This dissertation focuses on smallholders and how the reduction of food losses can help resolve the challenges of low productivity they face today. To properly understand the magnitude of losses, the dissertation develops

a definition of food loss. It then uses an innovative methodology to identify the quantity and quality of losses and where in the value chain they occur. Losses are quantified for a series of commodities produced by smallholders across several countries. The dissertation then examines the determinants behind losses across every stage of the value chain to find a solution to address them. Finally, a detailed analysis on perceptions is carried out to highlight farmers' lack of information on soil characteristics, and how this might contribute to food loss. The following is a more detailed description of each chapter.

The dissertation is divided in six chapters and a conclusion. The first Chapter is the introduction. Chapter 2 presents a literature review of what is known on measurement and the determinants of food loss, and the different interventions to reduce food loss across the value chain. This chapter identifies that food loss has been defined in many ways, and disagreement remains over proper terminology and methodology to measure it. Although the terms "post-harvest loss," "food loss," "food waste," and "food loss and waste" are frequently used interchangeably, they do not refer consistently to the same problem and the same aspects of the problem. Furthermore, none of these classifications includes pre-harvest losses, such as crops lost to pests and diseases before harvest, crops left in the field, crops lost because of poor harvesting techniques or sharp price drops, or food that was not produced because of a lack of proper agricultural inputs and technology. Consequently, figures on food loss are highly inconsistent and it is very difficult to compare them. In addition, the precise causes of food loss and where in the value chain they occur remain undetected, and success stories of reducing food loss are rare.

In chapter 3, we address the existing measurement gap by developing and testing three new methodologies to reduce measurement error and assess the magnitude, causes and costs of food loss, as well as the stages across the value chain where losses occur. Our proposed methods account for losses from pre-harvest to product distribution and include both quantity losses and quality deterioration. We apply the instrument to producers, middlemen, and processors in five staple food value chains in six developing countries. Comparative results suggest that losses are highest at the producer level and most product deterioration occurs before harvest. Aggregated self-reported measures, which have been frequently used in the literature, consistently underestimate actual food losses.

In chapter 4, a detailed analysis is conducted based on data collected from chapter 3 to understand what the main causes of food losses are. The results show that producers' education and experience and the number of years a producer has been involved in the production of a specific crop are significantly correlated with reduction of food loss. Unfavourable climatic conditions, pest, and diseases, as well as limited knowledge and access to equipment, credit, and markets also make it difficult to increase production of higher quality products, therefore contributing to food loss. The results reveal specific areas that require investments to reduce food loss and show considerable heterogeneity of food loss. The causes of food loss appear to be highly specific to context and type of commodity.

In chapter 5, we measure the gap between policymakers' and smallholder farmers' perceptions of soil characteristics and the soil variability. We find that in most of the plots, characteristics have difference in perception and did not show the real needs of the soils. This lack of information on soil characteristics and conditions could be an important determinant of the lack of adoption of the technological packages, and why sometimes they are not effective at all. The lack of information could be affecting farm productivity and increasing losses across the value chain.

Chapter 6 brings all the elements of the dissertation together. It discusses the conceptual framework behind the dissertation and the key hypothesis raising the importance of the mismeasurement of food losses. It also details the innovative process of data collection to measure food losses and soil characteristics, and the methodological innovations to identify the reasons for food loss and low adoption of new technologies. The synthesis chapter concludes that addressing food loss across the value chain first requires a common understanding of the concept by all actors. It also emphasizes the need for collaboration to collect better micro data across different commodities and contexts. Doing so will help target interventions and

identify required technologies, value chain infrastructure, and extension services to minimize losses. While there are commonalities, food loss is very context specific. The heterogeneity suggests that policies aiming at the reduction and prevention of food loss need to be developed with specific commodity and context in mind. Policymakers need to take into consideration the perception of farmers to respond to the reality they face.

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My fieldwork took place in many countries worldwide. In all these places, I learned a lot from the local researchers and survey takers, having a lot of incredible experiences and adventures while making many friends. Most of my data was collected during the first year of my PhD, and implementing and supervising the surveys in many languages and with different teams was very challenging. I want to thank the enumerators in each country with whom we have to go through very challenging moments. I am also thankful to Francisco Olivet for his incredible support in implementing the surveys in Guatemala and Honduras and the colleagues of the International Potato

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About the Author

Luciana Delgado was born in Lima, Peru, on 16 August 1986. In 2011, Luciana graduated as an engineer in Agronomy from National University Agraria La Molina (Peru). After an incredible field experience, in 2013, she joined the International Food Policy Research Institute (IFPRI), an international think tank in Washington DC, to learn more about the economics behind value chains and the role of policies at the local, regional, and global level.

Most of her career has been associated with global value chains, agroindustry, and food losses working at the International Food Policy Research Institute. She has also worked with the private sector in the agroindustry sector. She has developed expertise in strengthening agriculture research and development programs, upgrading value chains, measuring and interventions to reduce food losses across the value chain, and assessing market opportunities for linking smallholders to dynamic markets. She has excellent experience working with multidisciplinary teams and expertise in Latin America, Africa, and Asia.

Luciana started her PhD in January of 2017 in the Soil, Geography, and Landscape group of Wageningen University, where she combines the academic program with her work. During the PhD, Luciana has published journal articles in top journals, discussion papers, policy briefs and technical notes. She has also presented her work in several international conferences as the AAEA annual meeting, European Association of Agricultural Economics, American Agricultural Association Meeting, within others. Luciana has also taken several courses as the DSSAT International Training Program. Luciana had also been advisor of a master student at WUR and had given advice to other doctoral students. Finally, she had been awarded through competitive process several research grants and awards from the CGIAR, the Netherlands, and the Food and Agriculture Organization of the United Nations (FAO).

Peer review publications

Delgado, Luciana; Schuster, Monica; and Torero, Maximo. 2021. Food losses in food systems: What we know and what we do not. Forthcoming Annual Reviews of Economics.

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Publications in review

Delgado, L., Stoorvogel, J. 2021. An a priori analysis: the potential role of soil perception and soil variability in smallholder farmers' low adoption rates of agricultural practices in Central America. Submitted to Journal of Rural Studies

Working papers and reports

Delgado, Luciana; Nakasone, Eduardo; and Torero, Maximo. 2021. Can input access and market-based incentives reduce food loss? The case of bean farmers in Guatemala and Honduras. Washington, DC: International Food Policy Research Institute (IFPRI). https://ebrary.ifpri.org/digital/collection/p15738coll2/id/134918

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Conference presentations

Delgado, L., Schuster, M., and Torero, M. The reality of food losses: A new measurement methodology. The European association of agricultural economists; Parma, Italy (2017)

Delgado, L., Schuster, M., and Torero, M. The reality of food losses: A new measurement methodology. Agricultural & Applied Economics Association AAEA; Washington D.C., USA (2018)

Delgado, L., Schuster, M., and Torero, M. The reality of food losses: A new measurement methodology. World potato congress; Cusco, Peru (2018)

Delgado, L. Gaining efficiencies in the food system by reducing food losses across the value chain. APEC, Malaysia (2020)

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

The C.T. De Wit Graduate School PE&RC PRODUCTION ECOLOGY & RESOURCE CONSERVATION

Review of literature (6 ECTS)

- Improvement of marginal income through product choice to increase agricultural returns in Guatemala

Writing of Project proposal (4.5 ECTS)

- Improvement of marginal income through product choice to increase agricultural returns in Guatemala

Post-graduate courses (7.8 ECTS)

- GIS in practice; PE&RC & SENSE (2016)
- Basic statistics; PE&RC & SENSE (2017)
- Advanced statistics course design of experiments; PE&RC & WIAS (2017)
- The art of modelling; PE&RC & SENSE (2017)

Laboratory training and working visits (4.5 ECTS)

- DSSAT International training program assessing crop production, nutrient management, climate risk and environmental sustainability with simulation models: The University of Florida/ The University of Georgia/ Washington State University (2015)
- Methodology for the elaboration of land taxonomy and land capacity maps at a scale of 1: 50,000 in Guatemala (Mapa de Taxonomia de Suelos y Capacidad de Uso de la Tierra a escala 1: 50,000): Ministry of Agriculture, Livestock and Food Supply (MAGA), Guatemala (2015)

Invited review of journal manuscripts (4 ECTS)

- Agricultural & Applied Economics Association: food losses (2017)
- Food Policy: food losses (2020)
- Applied Economic Perspectives and Policy: food losses (2020)
- Annual Review of Economics: food losses (2020)

Deficiency, refresh, brush-up courses (3 ECTS)

- Tableau workshop: statistical and graphical analysis; Tableau (2015)
- Federal GIS conference; ESRI (2016)

Competence strengthening / skills courses (1.7 ECTS)

- Diversity training: working with different ethnic groups and issues to take into account (2014)
- Training certification IRB; Collaborative Institutional Training Initiative, CITI (2018)
- An introduction to LaTex; PE&RC (2020)

PE&RC Annual meetings, seminars and the PE&RC weekend (0.3 ECTS)

- PE&RC Last years online afternoon (2020)
- PE&RC Afternoon event (2020)

Discussion groups / local seminars or scientific meetings (6.2 ECTS)

- Tools for value chains network thematic discussion groups under the policies, institutions and markets CGIAR program (2016-2018)
- AGRODEP Modelling consortium network on value chains (2016)
- Professional speed dating at the ICABR conference (2018)

International symposia, workshops and conferences (8.5 ECTS)

- The European association of agricultural economists; Parma, Italy (2017)
- Agricultural & Applied Economics Association AAEA; Washington D.C., USA (2018)
- World potato congress; Cusco, Peru (2018)
- APEC; online, Malaysia (2020)

Lecturing / supervision of practical's / tutorials (2.7 ECTS)

- Losses along value chains training course (AGRODEP); Ghana (2016)
- Methodologies for the analysis of losses in food value chains; Peru (2017)
- Losses along value chains training course; Ghana (2017)
- Methodologies for the analysis of losses in food value chains; Ecuador (2018)

MSc thesis supervision

- Soil characterization, soil perception

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