Innovations in Measuring food losses[1]

Luciana Delgado[2], Monica Schuster[3], and Maximo Torero[4]

International Food Policy Research Institute

Abstract

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 seven staple food value chains in nine 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.

Keywords: food losses; supply chain; value chain, attributes, and categories

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[2] International Food Policy Research Institute, Luciana.Delgado@cgiar.org
[3] Division of Bio-economics, Department of Earth and Environmental Sciences, KU Leuven, Monica.Schuster@gmail.com
[4] Food and Agriculture Organization of the United Nations (FAO), Maximo.ToreroCullen@fao.org

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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). 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).[5] 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

[5] 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.

would likely comprise a mixture of methods, such as waste composition analysis, questionnaires, interviews, or waste diaries (WRAP, 2013).[6]

We quantify food loss through two 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 three 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 seven staple food value chains in nine countries (potato in Peru and Ecuador, maize and beans in Honduras and Guatemala, teff in Ethiopia, wheat in China, yam and groundnuts in Ghana, and maize in Tanzania and Mozambique). Applying this methodology to seven 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.

2. Divergence in terminology and definitions

The literature commonly agrees on the need to measure food loss along different value chain stages (Figure 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

[6] 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 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 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.[7] 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 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

[7] 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.

has important implications for the estimation methodology used to examine food loss and for the interpretation of results.

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 2).

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.[8] 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).

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

[8] 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.

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 2 summarizes the two approaches to FLW estimation, highlighting their advantages and drawbacks. Figure 3 provides a global overview of the magnitude of FLW from recent studies, distinguishing the two estimation approaches.[9] 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). 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.

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).[10] Rooted in this definition, goals for reducing food loss and waste must include both quantitative and

[9] 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).

[10] 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.

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 must also take into account that food loss and waste often originate at different stages along the value chain in different geographical locations.[11]

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).

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 three

[11] 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).

methodologies can measure losses at different stages of the value chain and can be applied across crops and regions. The methodologies are based on 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 three 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.[12] Middlemen and processors are asked about losses at different stages of post-harvest

[12] 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 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.[13]

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

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

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:

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

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

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.[14] 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*.[15] 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.

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:

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

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

[14] 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.
[15] 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.

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 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.[16] 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 affected by the inferior damage attributes, both after production and after post-harvest.[17] 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.

[16] 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).
[17] 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 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:

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

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

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).

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.

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:

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

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

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 three 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.[18] The second module asks about the quantity of affected (quality degradation)[19] and the quantity totally lost (quantity degradation)[20] 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.

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.

[18] 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.

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

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

Each crop has its own damage coefficient, determined using international classification in collaboration with local experts.[21]

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.[22] We confirm through expert consultations and in the different markets the price punishment that each of these types of crop damage entails.

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

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

[22] 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.

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.

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.

In Tanzania, maize is the primary staple crop, that is growing in most of the agroecological zones of the country. Tanzania is a major producer of maize in Sub- Saharan Africa. In 2019, Tanzania produced about 5.7 million metric tons of maize each year in approximately 3.4 million hectares of land (FAOSTAT, 2019) and in 2013/14 growing seasons, Tanzania produces over half billion metric tons of maize, and 85% of this maize was produce by smallholders (Suleiman et.al. 2015). The Annual

Agriculture Sample Survey (AASS) 2016/2017 was used to identify the potential maize production. Our surveys were organized between September and December of 2020, covering the regions of Dodoma, Iringa, Lindi, Mbeya, Ruvuma, Singida and Morogoro.

Maize in Mozambique is the main staple food that is grown in more than two-thirds of rural households and the production take place in all the provinces but is more intense in the northern and central parts (Cugala et.al. 2012). In 2019 growing seasons, Mozambique produced over 2 million metric tons of maize in approximately 2.6 million hectares of land (FAOSTAT, 2019), and 95% of this maize was produce by smallholders (Mutungi et.al. 2013). Our surveys were organized in February of 2020, covering the provinces of Manica and Zambezia.

In Ghana, yam was chosen due to its importance in Ghanaian agriculture. Ghana is the second largest producer of yam in the world (only under Nigeria): in 2019 the country cultivated 462 thousand hectares and produced 8.2 million tons of this crop (FAOSTAT, 2019). It is also an important staple crop and accounts for 11% of the food consumption (Anaadumba 2013). Groundnuts were chosen due to its economic importance, gender component, and nutritional potential. Groundnuts have been traditionally considered a "female crop".; in 2019, Ghana produces 535 685 tonnes of groundnuts with shell in approximately 403 thousand hectares. The majority of groundnuts women produce (over 80% plus in some places) goes towards household consumption, using any additional surplus for sale to local traders or in local markets as an income-generating activity to augment family income. The data was collected throughout the first quarter of 2019 in twelve districts: three in the Upper West Region (Nandom, Wa Municipal, and Wa West), three in the Upper East Region (Kasena Nankana West, Kasena Nankana Municipal, and Talensi), and six in the Nothern Region (Yendi Municipal, Mion, Nanumba North, Nanumba South, East Gonja, and West Gonja).

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 1 reports the sample size (N) of producers, middlemen, and processors in each country. Tables 2-4 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 men than women (with the exception of Ghana, 86 and 89 percent of all middlemen are women in yam and groundnuts). 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, for maize in Mozambique and for tam and groundnuts in Ghana, the wholesalers/transformers are mainly female; in the wheat and potato sector and maize in Tanzania, wholesalers are predominantly male.

6. Results

Figure 4 shows loss levels at the producer, middlemen, and processor levels separately and alternatively for the three estimation methodologies (i.e., aggregated self-reported (S), category (C), and attributes (A)). Some observations are discarded due to missing values and outliers.[23] 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.

[23] 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.

As shown in Figure 4, loss figures across all value chains fluctuate between 6 and 35 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.

Causes of food losses

Figure 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. In Ecuador, Peru and Ghana, worker shortages or excessive labor costs are important limiting factors. Rot in Ghana was also an important reason to left yam in the field. In China, Ghana and Mozambique, 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, Ethiopia, Ghana, Mozambique and Tanzania; are damage to crops done by workers during harvesting or sorting, because of their lack of training and experience.[24] 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. In Ghana, Mozambique and Tanzania; plagues, rodents and animals were the main cause of post-harvest losses. 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.

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 two 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 two new methodologies. We apply them to producers, middlemen, and processors in seven staple food value chains in nine developing countries.

[24] For further details on determinants of food losses, see Delgado et al. (2020).

The estimation results from the two 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 two 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.[25] 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 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.

[25] 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.

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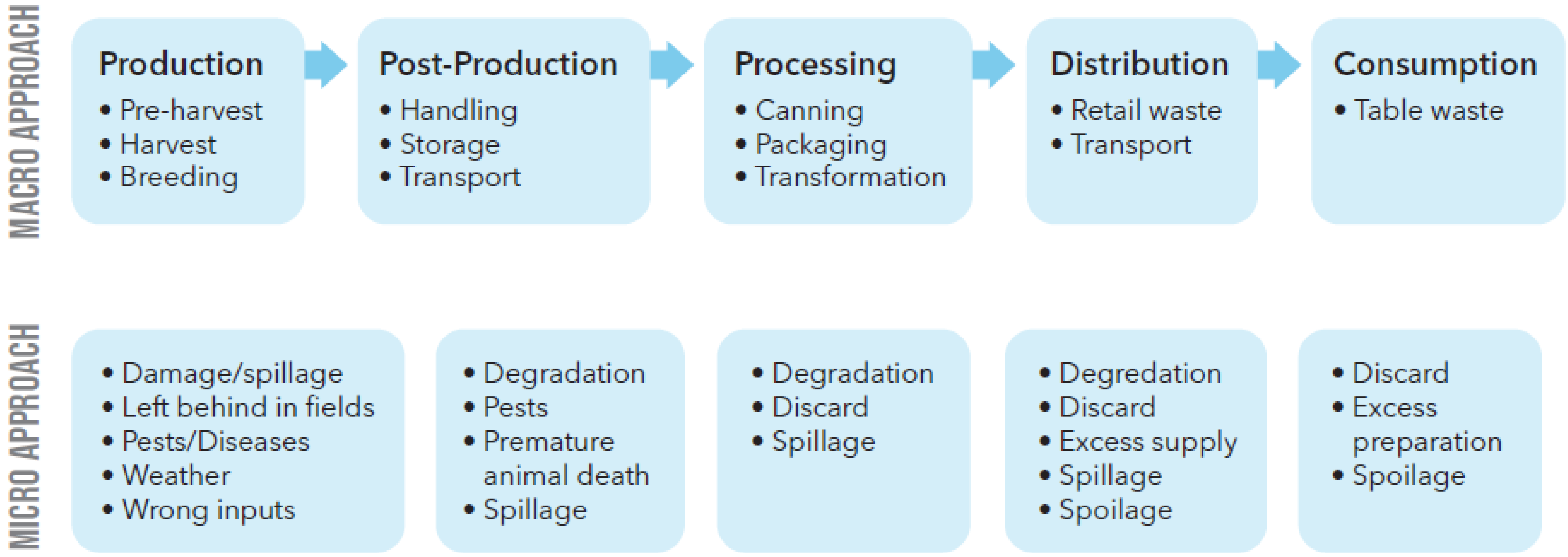
Figure 1: Food Losses along the Value Chain



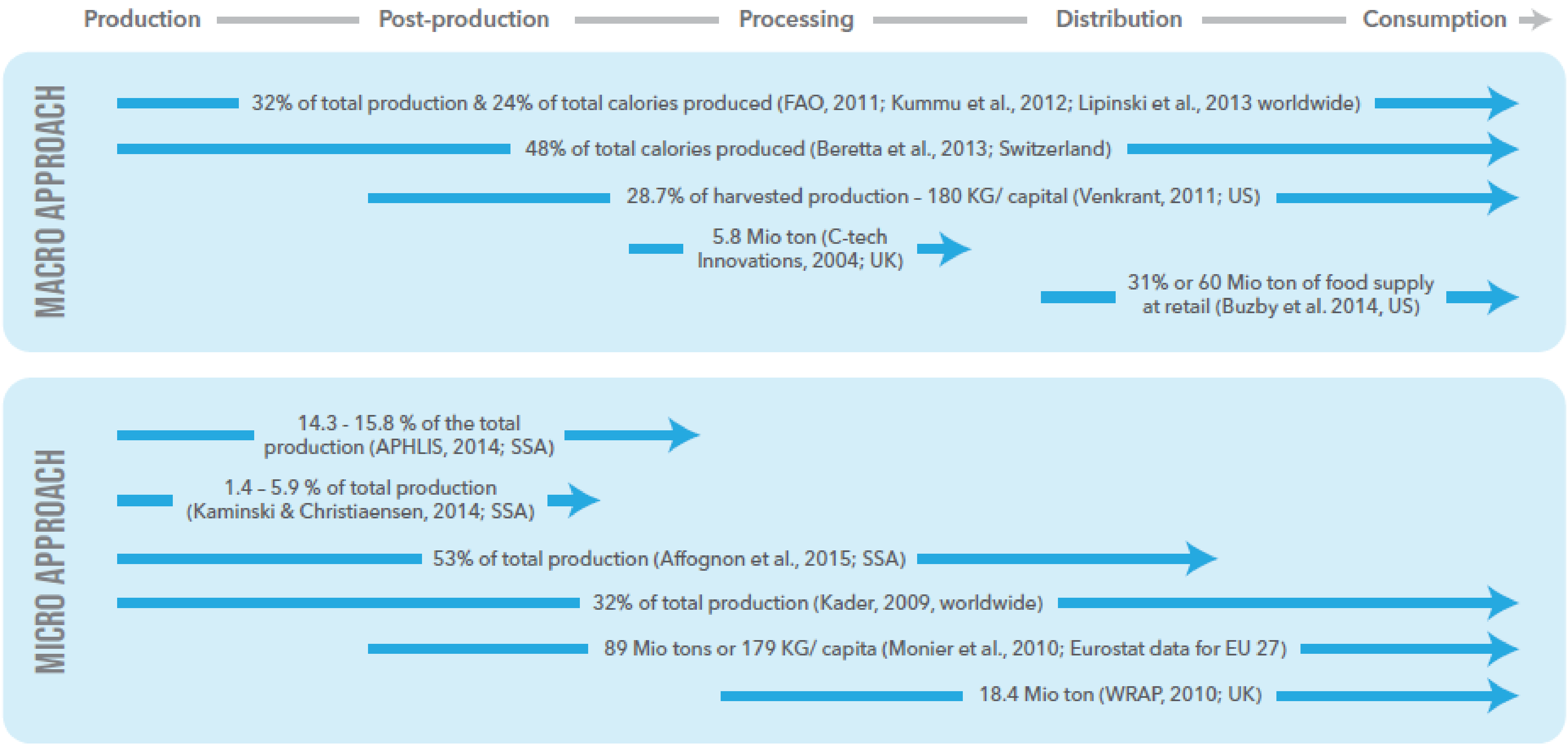
Note: author's elaboration

Figure 2. Food Losses Estimation Methodologies

	DATA & METHODS	PROS	CONS
MACRO APPROACH	**Data:** National or regional aggregated statistics **Methods:** • Mass- and energy balances: comparison of raw material input and produced output	• Cheap and straightforward implementation • Representative for large region and good comparability	• High requirements on data quantity, quality and standardized collection methodologies • Not representative for specific regional units • No distinction between: o VC stages where loss occurs o Natural and unnatural loss o Edible and non-edible loss
MICRO APPROACH	**Data:** data on a sample of value chain actors, often collected ad-hoc **Methods:** • Questionnaires and interviews • Food loss and waste diary • Direct measurement, through weighing or volume assessment • Scanning	• Commodity, climatic zone and context specific • Detailed, fully relevant and VC stage specific data • Insights into causes and prevention possibilities	• Costly and time consuming • Representativeness highly sensitive to sampling choices • Sensitive to the estimation timing • Estimates are often not comparable, and cannot be generalized • Same estimation method can often not be applied to all VC stages

Note: author's elaboration

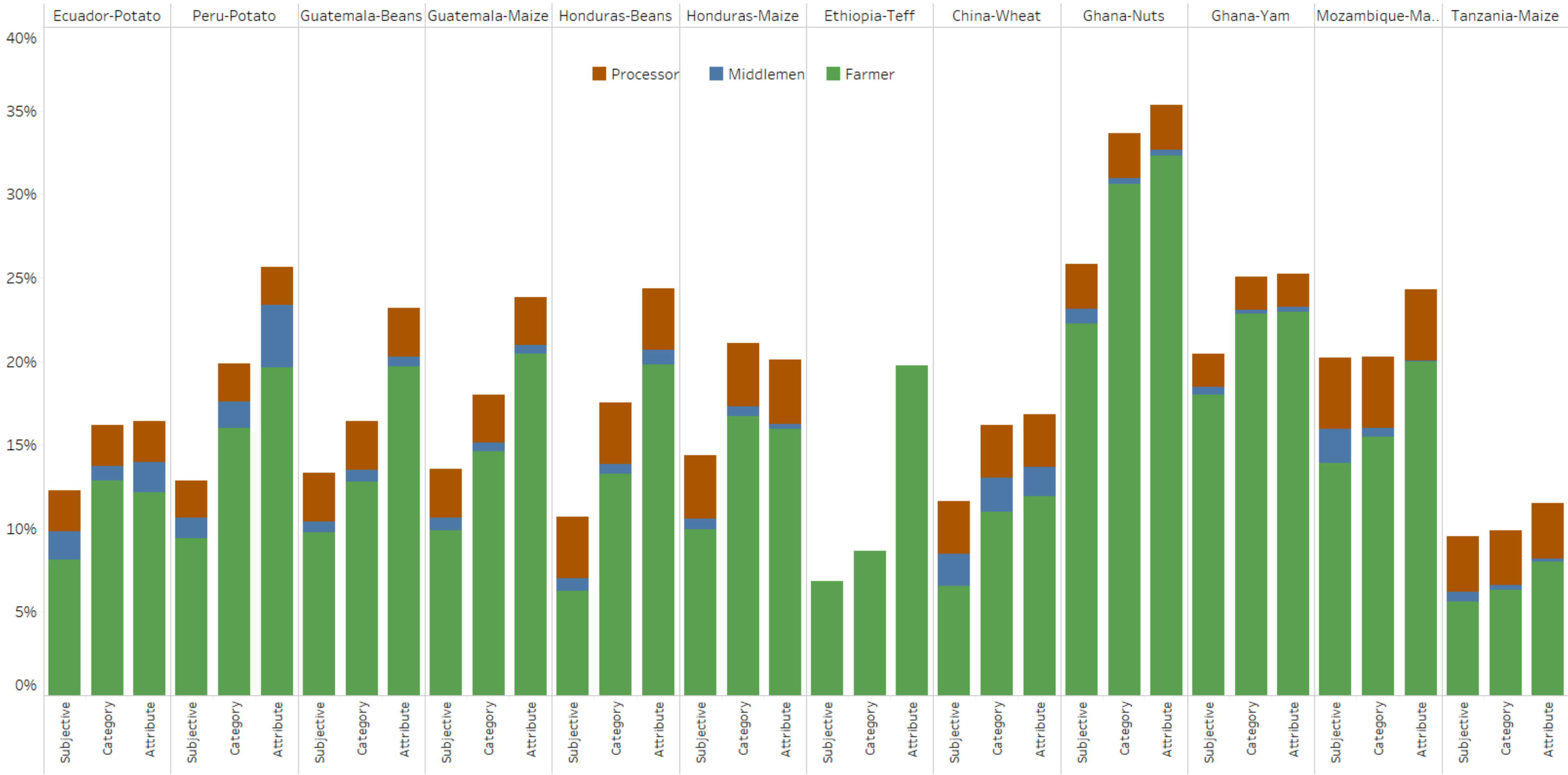
Figure 3. Estimation of Food Losses



Note: author's elaboration

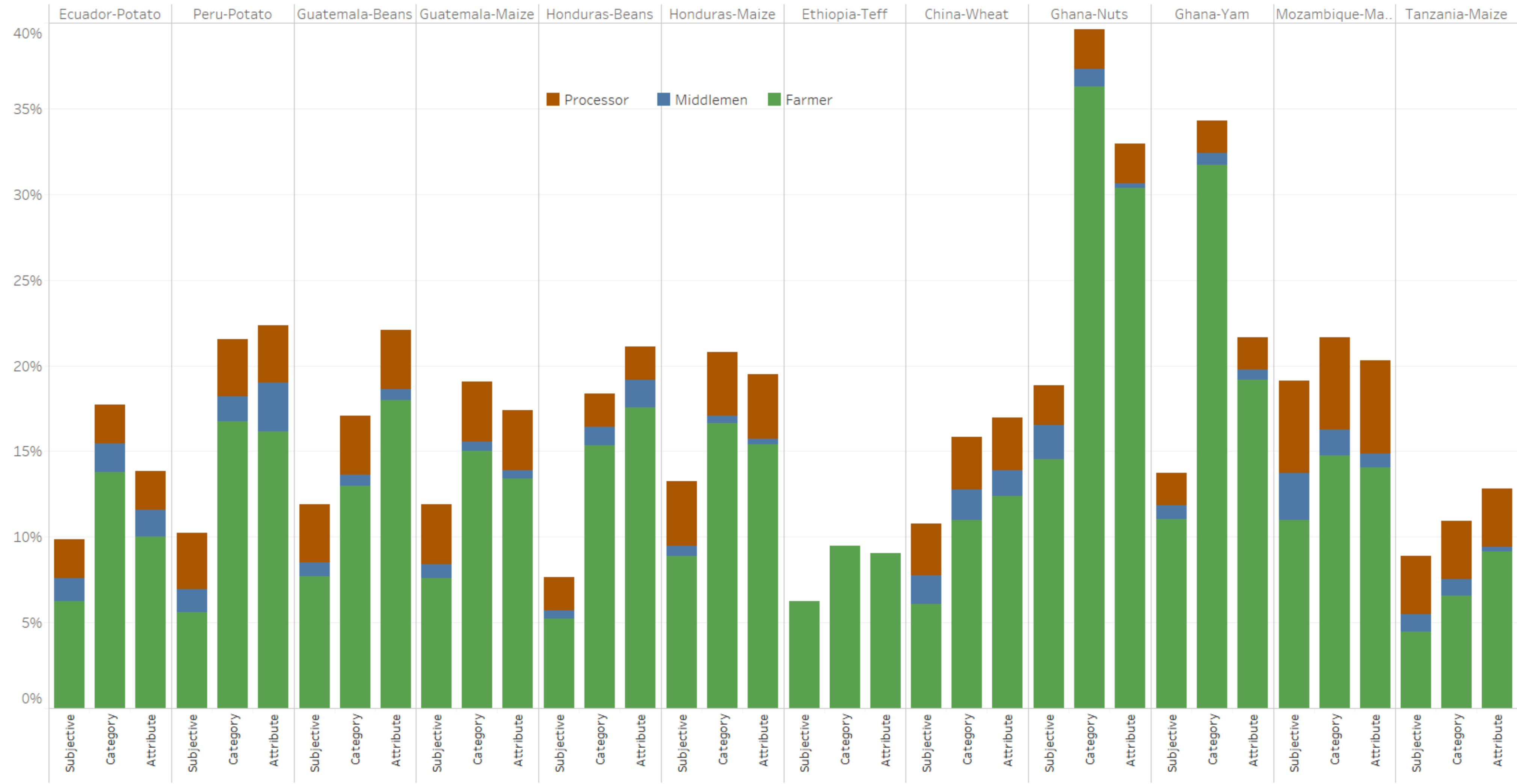
Figure 4: Quantitative and Qualitative Food Loss along the Value Chain, Estimated Using Three Methodologies

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



^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)



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

Figure 5: Self-Reported Causes of Losses

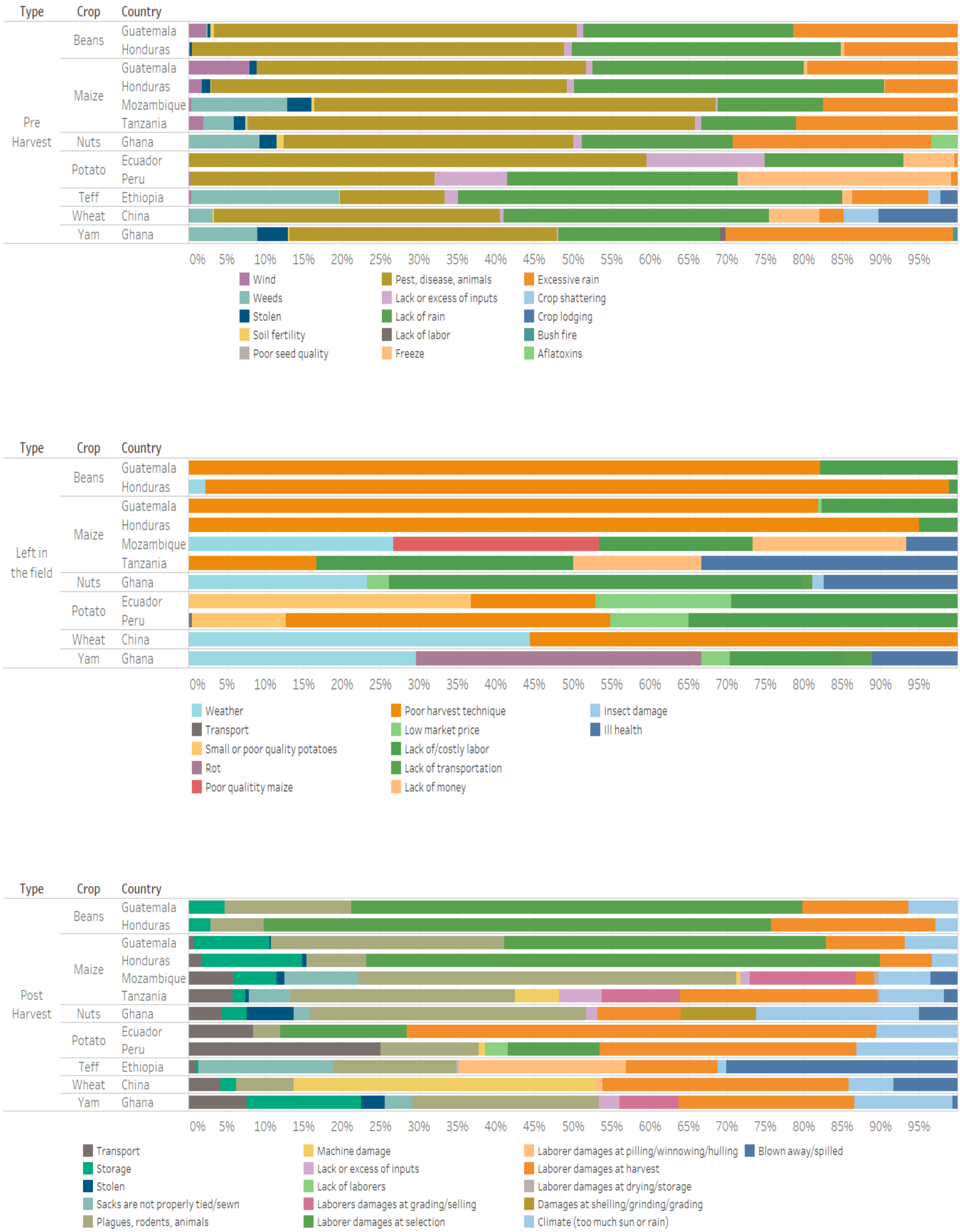


Table 1: Sample Size

	Ecuador	Peru	Honduras	Guatemala	Ethiopia	China	Tanzania	Mozambique	Ghana
Producer	302	411	1209	1155	1203	1114	770	774	884
Middlemen	182	85	325	365	---	140	159	203	374
Processor	147	139	224	245	---	53	89	100	225
Total	**631**	**594**	**1758**	**1765**	**1203**	**1307**	**1018**	**1077**	**1483**

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.

Table 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)		Tanzania: maize (N = 770)		Mozambique: maize (N = 774)		Ghana: Yam (N = 442)		Ghana: Nuts (N = 442)	
			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	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	70.00%	0.46	63.00%	0.48	92.68%	0.26	42.51%	0.49
	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	45.20	12.37	43.88	14.47	42.29	13.56	41.40	12.28
	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	5.00%	0.21	12.00%	0.32	67%	0.47	66%	0.47
		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	82.00%	0.39	72.00%	0.45	8.87%	0.28	17.00%	0.38
		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	13.00%	0.34	16.00%	0.37	18.85%	0.39	13.42%	0.34
		>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	1.00%	0.07	0.00%	0.00	2.00%	0.14	1.79%	0.13
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	3,608	7,652	2,094	3,807	4,102	6,286	312	783
	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	2.08	5.07	1.93	1.93	1.35	1.12	0.99	0.76

Table 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)		Tanzania: maize (N = 159)		Mozambique: maize (N =203)		Ghana: Yam (N = 182)		Ghana: Nuts (N = 192)	
		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	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	88.00%	0.33	75.00%	0.44	14.84%	0.36	10.94%	0.31
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	39.00	8.33	36.00	9.82	41.80	11.01	42.63	11.31
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	73.58%	0.44	82.75%	0.38	68.68%	0.47	54.69%	0.50
	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	26.42%	0.44	17.24%	0.38	31.32%	0.47	45.31%	0.50
	retailer	12.64%	0.33	2.35%	0.15																		

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 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)		Tanzania: maize (N = 89)		Mozambique: maize (N =100)		Ghana: Yam (N = 113)		Ghana: Nuts (N = 112)	
	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	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	90.00%	0.30	16.00%	0.37	0.88%	0.09	1.79%	0.13
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	44.00	9.86	36.00	10.17	39.83	10.02	42.13	10.45
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	1.39	0.49	1.04	0.20	0.94	0.33	1.06	0.63

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.

APPENDIX

Table 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?