Received: 25 August 2020 | Accepted: 25 January 2021

DOI: 10.1002/aepp.13156

AAEA INVITED PAPER

On the origins of food loss

Luciana Delgado[1] | **Monica Schuster**[2] | **Maximo Torero**[3]

[1]International Food Policy Research Institute (IFPRI), Washington, DC, USA

[2]Division of Bio-economics, Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium

[3]Food and Agriculture Organization of the United Nations (FAO), Rome, Italy

Correspondence
Luciana Delgado, International Food Policy Research Institute (IFPRI), Washington, DC, USA.
Email: luciana.delgado@cgiar.org

Editor in charge: Daniel Petrolia

Abstract

In this paper, we try to understand what the main causes of food losses (FLs) 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, pests, and diseases, as well as limited knowledge and access to equipment, credit, and markets, are also challenges to increasing production of higher quality and therefore reasons for FL. Policies to reduce and prevent FL need to be targeted to specific commodities and contexts.

KEYWORDS

crop, food, food losses, loss, perishable, post-harvest, storage

JEL CLASSIFICATION

Q13; Q18; Q58

Why does so much food get lost along the food value chains? Little is known about what causes food loss (FL) 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. FL 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 FL can help develop the right interventions. Even though it would be impossible to completely eliminate FL and waste, experts agree that there is room for reducing FL and waste.

[The copyright line for this article was changed on 08 April 2021 after original online publication.]

We implemented specially designed surveys to capture FL 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 FL and a rich set of socioeconomic 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 FL data. FL is defined through the "attributes method" (see details in Delgado et al., 2020). The results reveal specific areas that require investments to reduce FL. They also show considerable heterogeneity of FL. The causes of FL appear to be highly specific to the context and type of the commodity.

This paper is organized as follows. The introduction is followed by a literature review (Section 2) on the causes of FL and waste in developing countries. Section 3 presents the data and empirical approach. Section 4 presents descriptive statistics and key findings for Ethiopia, Ecuador, Honduras, Guatemala, Peru, China, and Mozambique. Section 5 discusses the findings with respect to the scientific literature. The paper ends with conclusions and policy recommendations.

LITERATURE REVIEW ON THE CAUSES OF FL

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); and 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 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, the higher the education, the 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 FL in many contexts.[1] In African countries, there is high dependence on sun-drying of crops among small-holder farmers. Post-harvest rainfall could lead to substantial losses if crops are not dried properly before being stored or taken to the market.

Insects and pest attacks on produce have also been identified as important causes, typically compounded by heat or moisture and poor storage conditions (Chegere 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% 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 0.6%–1% depreciation in the value of maize. Certain climatic conditions, especially heat and

TABLE 1 Literature review on the origins of food loss (FL)

Author	Country/area	Commoditty	Cause	Effect on losses
Adewumi et al. (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)	Negative
			Wholesale Market Level: loading method (dummy: stacking boxes vs. open loading)	
Aidoo, Danfoku, and Mensah (2014)	Ghana	Tomato	Gender (female), farm size, days of storage	Positive
			Household size, membership of FBO, use of improved tomato variety	Negative
Ambler, De Brauw, and Godlonton (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, Tetteh, and Donkoh (2017)	Ghana	Yam	Income, education	Positive
			Market participation, age, distance to the district capital	Negative
Basavaraja, Mahajanashetti, and Udagatti (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

TABLE 1 (Continued)

Author	Country/area	Commoditty	Cause	Effect on losses
Chegere (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 weather, 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 weather, 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 disinfected, used storage protectants (using chemical protectants and ashes for storage pests, and poisons and traps for rats), percent sold 3 months after harvest, area planted maize, education **Marketing losses as a proportion of amount sold:** gender (male), number of acting workers, area planted maize	Negative
Doki et al. (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

(Continues)

TABLE 1 (Continued)

Author	Country/area	Commoditty	Cause	Effect on losses
Gebretsadik, Haji, and Tegegne (2019)	Ethiopia	Sesame	Land size, distance of sesame farm from residence, total amount of sesame production, weather condition (wind and rain happening during harvesting to threshing time), distance piles transported to threshing place, number of drying/stacking days, mode of transportation (tractor/tracker vs. car/donkey),	Positive
			Education level, extension service contact	Negative
Ismail and Changalima (2019)	Tanzania	Maize	Mode of transportation, storage time, quantity of maize transported, methods for processing	Positive
			Post-harvest training, use of storage facility	Negative
Khatun and Rahman (2019)	Bangladesh	Eggplants	Total harvested amount, selling place (dummy: market level vs. farm level)	Positive
			Respondents' education, packaging (dummy: improved vs. traditional)	Negative
Kikulwe et al. (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),	Positive
			Retail: Availability of information (vs. quality information)	
			Producer: distance to tarmac road, distance to market, district (Rakai), education level (secondary), district * distance to tarmac road (Rakai district = 1)	Negative
			Retail: gender (female), group member (vs. no member), buy from nearby markets (vs. buy from suppliers), buy from producers directly (vs. buy from suppliers)	
Kuranen-Joko and Liambee (2017)	Nigeria	Tomato	Farm size (ha), labor type (family labor vs. otherwise)	Positive
			Farming experience	Negative

TABLE 1 (Continued)

Author	Country/area	Commoditty	Cause	Effect on losses
Macheka et al. (2018)	Zimbawe	Tomato	Market price stability, harvest time (level of maturity required for costumers), determined processing volumes (any quantity vs. specific quantity defined 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 and Selejio (2019)	Tanzania	Maize	Gender (male), age, harvest working days, use of hired labor, storage protectorants	Positive
Paneru, Paudel, and Thapa (2018)	Nepal	Maize	Early harvest, storage structure for shelled grain (jute bag), Storage period for de-husked cobs	Positive
			Altitude, occupation 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

(Continues)

TABLE 1 (Continued)

Author	Country/area	Commoditty	Cause	Effect on losses
Shee 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 technique (sticks vs. bare hands), place of sale (local market vs. farm gate)	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), milling technique (manual mill vs. commercial hammer mill)	Negative
		White-fleshed sweet potato	Age of householder, 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 sweet potato	Transport technique (by motorcycle vs. in sacks carried by hand)	Positive
			Education level, training on PHL management	Negative

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 an important factor behind the losses of horticultural crops, and lack of transportation facilities for losses of maize crops.

The risk of FL 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% and 36% of losses in maize grains in Africa. Insufficient drying, excessive drying, and missing grains are some of the problems of the harvesting and drying stages. Other problems such as 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 losses occur in maize. Studies also point to credit constraints as a main bottleneck to technology adoption, preventing FL reduction.[2]

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 PHLs 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 PHLs, 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 PHLs are correlated with farm size. Larger farms are more likely to incur PHLs but experience fewer losses in the intensive margin. The overall impact suggests a negative relationship between the share of PHLs and farm size.

DATA AND METHODS

Data

We developed and implemented detailed surveys that allowed us to quantify the extent of FL at the producer level, using approaches that are comparable across commodities and regions. The survey enabled us to characterize the nature of FL, 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, Schuster, & Torero 2017, 2020).

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, 411 potato farmers in Peru, 1209 maize and beans farmers in Honduras, 1155 maize and beans farmers in Guatemala, 1203 teff farmers in Ethiopia, 1114 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 FL along the commodity value chains, in this paper we adhered to what has been defined the "attribute method" (see Delgado, Schuster, & Torero 2020). 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 FL that have been used in other studies (Compton & Sherington 1999; Delgado, Schuster, & Torero 2020).

Empirical approach

We used a statistical framework to assess the association between different socioeconomic and production factors and FL 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 socioeconomic 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 $FL_{i,c,x}$ is an indicator of FL of producer i 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. $X_{i,\mathrm{c,x}}$ are a set of socioeconomic characteristics, $Z_{i,c,x}$ are agricultural production characteristics, and $N_{i,c,x}$ are post-harvest managing and handling techniques, including storage. $W_{i,c,x}$ is a proxy for production issues highlighted by the producer during the 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, $W_{i,\mathrm{c,x}}$ captures external growing conditions and limitations. Finally, location-fixed effects π_v 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. $\varepsilon_{i,c,x}$ is the unobservable error term.

We use classical maximum likelihood estimation to assess the parameters $\hat{\beta}$. 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 & Wooldridge 1996, 2008).[3] We calculate the 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.

RESULTS

Producer characteristics

Table 2 shows summary statistics of the producers across the different countries and commodity groups. Around 90% 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 have also completed secondary education. Producers are rural smallholders. They cultivate between 0.35 ha (beans in Guatemala) and 3.5 ha (potato in Ecuador) of land. 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% 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 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 5 months (beans and maize value chains in Guatemala and Honduras; teff value chain in Ethiopia). About 50% of all wheat farmers in China and 30% of all potato farmers in Peru store their produce for an average of 1 month. Only farmers in Ecuador rarely store the potatoes they grow. Around 63% of all farmers store their produce in their house in bulk or in bags. Around 14% of all farmers store them in traditional storage facilities. Less than 10% of farmers use metal or plastic silos, with the exception of maize farmers in Honduras.

TABLE 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	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Socioeconomic 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 (ha)		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

TABLE 2 (Continued)

Variable name			Ecuador: Potato ($N = 302$) Mean	SD	Peru: Potato ($N = 411$) Mean	SD	Guatemala: Beans ($N = 450$) Mean	SD	Honduras: Beans ($N = 685$) Mean	SD	Guatemala: Maize ($N = 922$) Mean	SD	Honduras: Maize ($N = 1024$) Mean	SD	Mozambique: Maize ($N = 774$) Mean	SD	Ethiopia: Teff ($N = 1203$) Mean	SD	China: Wheat ($N = 1114$) Mean	SD
Post harvest[f]	No. 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 winnowing		*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 (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			61%	0.49	30%	0.46
		House (bulk)	*na*												39%	0.49	*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
Sales		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

[a]Includes fertilizers, insecticides, herbicides, and fungicides.
[b]Includes activities such as irrigation, trimming, and pruning.
[c]Includes machine-driven activities, such as soil preparation, sowing, pest control, fertilizer application, weeding, mulching, cutting, and harvest.
[d]Includes activities such as selection, classification, drying, etc.
[e]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.

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

Likelihood and magnitude of FL

Table 3 provides insight into the likelihood of FL 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. (2020). The methods assume that the producer evaluates the 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.[4] 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 3).

Table 3 shows that most farmers suffered at least some weight or value loss in the previous harvest season. The figure ranges from 64% of all teff farmers in Ethiopia to 95% of all wheat farmers in China and 97% of all maize farmers in Guatemala. On average, 20% of the farmers' produce was lost. Figures range from 14% of all products lost in the potato value chain in Ecuador to 31% loss in the teff value chain in Ethiopia. Percentage losses expressed in value tend to be 4% 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.

TABLE 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	1186	64%	31%	14%
China – Wheat	1099	95%	12%	13%

Note: Estimation of the loss through the "attribute method" (see Delgado, Schuster, & Torero 2020).
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 4–8 presents the 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 FL in five groups: socioeconomic 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 FL 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.

Socioeconomic characteristics

Most farmers are men, but there is no clear gender pattern in FL across countries and commodities. For example, being a male farmer tends to be correlated with 4.9% to 10.9% less points share 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. No correlation with gender is detected in other commodity value chains. Age, education, and experience tend to be negatively correlated with the probability and share of FLs. In particular, being older is associated with about 3% points less likelihood to incur in a loss in the maize value chain in Guatemala and Honduras. Formal education, such as primary, secondary, or higher education, significantly correlates with 5%–30% 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% points less likelihood of any loss in Peru and with 14% and 68%, respectively, points less share of FL in Ecuador and Peru). This result is in line with the outcome we find on crop cultivation experience.

Market access

The cost or time to reach markets has 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 kilogram of produce to reach a market or the time—in 10 hours—to reach a market, can increase the share of produce loss by an average of 0.4% 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 the lack of access to markets and credits as a challenge to increasing production of high-quality products.

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

TABLE 4 (Continued)

	Ecuador		Peru	
	Probit	**GLM**	**Probit**	**GLM**
Location-fixed effects	Parroquia	Parroquia	District	District
Agroecological zone	Yes	Yes	Yes	Yes
No. of Observations	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]Includes fertilizers, insecticides, herbicides and fungicides.
[b]Includes irrigation, "aporque" and "corte del yuyo".
[c]Machine-driven activities include soil preparation, sowing, pest control, fertilizer application, weeding, "aporque," "corte del yuyo," harvesting.
[d]This refers to selection, classification, drying, and "acarreo" after drying.

TABLE 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	
Socioeconomic 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]			−0.012	−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*	0.000	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)

TABLE 5 (Continued)

		Guatemala				Honduras			
		Probit		GLM		Probit		GLM	
Post-harvest activities	Storage dummy			0.128*** (0.045)		0.199*** (0.045)		0.072*** (0.027)	
	No. of post-harvest activities[d]	−0.026 (0.025)	−0.027 (0.025)	−0.027** (0.012)	−0.029** (0.013)	0.032 (0.025)	0.043* (0.023)	0.020 (0.020)	0.030 (0.019)
	Mechanical drying and winnowing	0.047 (0.260)	0.028 (0.272)	−0.207*** (0.078)	−0.239*** (0.080)	0.101* (0.053)	0.080 (0.051)	0.007 (0.050)	−0.019 (0.026)
	Mechanical threshing activity					0.102** (0.043)	0.130** (0.064)	0.110*** (0.030)	0.104*** (0.034)
	Mechanical transport	0.102** (0.049)	0.113** (0.055)	0.055* (0.029)	0.067** (0.029)	−0.069 (0.074)	−0.068 (0.066)	−0.006 (0.031)	−0.006 (0.033)
Storage	Storage time (in months)		0.001 (0.005)		−0.003 (0.003)		0.007 (0.008)		0.011*** (0.004)
	Storage: modern vs. traditional storage		−0.183** (0.076)		−0.162*** (0.052)		0.021 (0.044)		−0.018 (0.023)
	Number of storage conservation activities[e]		−0.026 (0.030)		0.012 (0.012)		−0.01 (0.057)		−0.040* (0.022)
Production problems and limitations to produce high quality (as perceived by the producer)	Climate	0.097*** (0.028)		0.033 (0.024)		0.079*** (0.024)		0.061*** (0.020)	
	Animals/rodents	0.129 (0.101)		0.051*** (0.016)		0.277*** (0.056)		−0.007 (0.023)	
	Pests	0.041 (0.035)		0.028 (0.023)		−0.026 (0.020)		0.034 (0.023)	
	Diseases	−0.012 (0.040)		0.055** (0.022)		0.022 (0.017)		0.027 (0.018)	
	Limited market access	−0.022 (0.049)		0.015 (0.028)		0.140*** (0.027)		0.123*** (0.042)	

(Continues)

TABLE 5 (Continued)

	Guatemala				Honduras			
	Probit		**GLM**		**Probit**		**GLM**	
Location-fixed effects	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality
Agroecological zone dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	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. For Guatemala, in the PROBIT model a significant number of observations are lost because of perfect prediction.

[a]Includes fertilizers, insecticides, herbicides and fungicides.

[b]Includes irrigation and "chapeo".

[c]Machine-driven production activities include cleaning, sowing, herbicide application, pest control, fertilizer application, and harvest.

[d]Refers to winnowing (sopla), threshing (desgrane), drying, putting in bags, and transport.

[e]Includes chemical fumigation, natural fumigation, and ventilation. The second column of each model reports results conditional on storage.

TABLE 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	
Socioeconomic variables	Male producer	0.095*** (0.036)	0.101** (0.049)	0.052** (0.025)	0.052** (0.023)	0.085*** (0.022)	0.065 (0.040)	−0.010 (0.025)	−0.020 (0.033)	−0.022* (0.012)	−0.011 (0.009)	−0.005 (0.012)	0.003 (0.011)
	Age of producer (in 10 years)	−0.003** (0.001)	−0.004*** (0.001)	0.001 (0.001)	0.000 (0.001)	−0.002** (0.001)	−0.003*** (0.001)	−0.001* (0.001)	−0.001 (0.001)	0.001*** (0.000)	0.000 (0.000)	0.001*** (0.000)	0.000 (0.000)
	Education: primary (vs. no education)	−0.141** (0.070)	−0.123 (0.092)	−0.024 (0.028)	−0.033 (0.030)	0.016 (0.010)	0.005 (0.013)	0.006 (0.018)	0.004 (0.019)	−0.023 (0.036)	−0.032 (0.033)	−0.005 (0.035)	−0.003 (0.012)
	Education: secondary or higher (vs. no education)			−0.003 (0.029)	−0.018 (0.040)	−0.014 (0.019)	0.010 (0.063)	−0.002 (0.058)	0.008 (0.059)	−0.021 (0.048)	−0.029 (0.032)	−0.002 (0.040)	−0.019*** (0.001)
	Experience in cultivation of maize (in 10 years)	0.001 (0.016)	0.017 (0.012)	−0.012** (0.005)	−0.005 (0.005)	0.019 (0.020)	0.025 (0.021)	0.009 (0.010)	0.009 (0.010)	−0.024*** (0.009)	−0.007*** (0.000)	−0.022 (0.014)	0.002 (0.007)
Market	Cost to reach market (USD/kg)	−0.043 (0.027)	−0.004 (0.046)	0.037*** (0.012)	0.033*** (0.012)	−1.406 (0.993)	−0.183 (1.025)	−0.101 (0.759)	0.027 (0.705)				
	Time to reach market (in 10 hours)									−0.023 (0.034)	−0.013 (0.021)	−0.028 (0.035)	0.023*** (0.004)
Production	Time of planting: primera vs. postrera			−0.064 (0.047)	−0.047 (0.048)	0.007 (0.023)	−0.024 (0.029)	0.029* (0.017)	0.024 (0.019)				
	Log(total production maize)	0.004 (0.029)	−0.057** (0.023)			0.028*** (0.009)	0.027*** (0.009)			0.065*** (0.013)	0.067*** (0.011)		
	Improved seeds (dummy)	−0.055** (0.024)	−0.061 (0.041)	−0.015 (0.015)	−0.007 (0.011)	−0.033 (0.023)	−0.044* (0.025)	−0.033* (0.020)	−0.031* (0.018)	−0.032 (0.020)	−0.023 (0.015)	−0.027 (0.024)	−0.022 (0.053)
	Resistant variety									−0.032 (0.025)	−0.042 (0.034)	−0.024 (0.023)	0.013 (0.014)
	Number of different inputs applied[a]	0.000 (0.023)	0.020 (0.028)	−0.013* (0.007)	−0.006 (0.010)	0.012 (0.008)	0.019*** (0.006)	−0.004 (0.010)	0.009 (0.011)	−0.007 (0.020)	−0.017 (0.019)	0.001 (0.017)	−0.007*** (0.002)
	Number of different field maintenance activities[b]			0.010 (0.049)	0.004 (0.029)	−0.019 (0.029)	−0.022 (0.029)	−0.007 (0.022)	0.001 (0.023)				
	Number of production activities done mechanically[c]	0.073** (0.030)	−0.047 (0.046)	0.034*** (0.009)	0.032*** (0.012)	−0.010 (0.010)	−0.022 (0.015)	0.012 (0.008)	0.006 (0.015)	−0.044*** (0.014)	−0.045*** (0.013)	−0.040* (0.021)	−0.004 (0.011)
	Hired labor for harvest	0.004 (0.036)	0.066 (0.042)	0.007 (0.012)	0.006 (0.012)	0.009 (0.040)	0.035 (0.042)	0.022 (0.035)	0.050* (0.027)	−0.003*** (0.000)	−0.003 (0.004)	0.041** (0.019)	−0.003 (0.027)

(Continues)

TABLE 6 (Continued)

		Guatemala				Honduras				Mozambique			
		Probit		GLM		Probit		GLM		Probit		GLM	
Post-harvest activities	Storage dummy			−0.031 (0.038)		0.068** (0.031)		0.057*** (0.020)		0.137*** (0.019)		0.124*** (0.013)	
	No. of post-harvest activities[d]	−0.068*** (0.022)	−0.066*** (0.018)	0.015* (0.009)	0.018** (0.008)	0.002 (0.009)	−0.003 (0.012)	0.001 (0.009)	0.003 (0.009)	0.024*** (0.005)	0.018 (0.019)	0.032*** (0.009)	
	Mechanical drying and winnowing	0.140 (0.107)	0.033 (0.118)	0.018 (0.014)	−0.007 (0.011)	−0.058 (0.049)	−0.110*** (0.025)	−0.024 (0.026)	−0.022 (0.036)				
	Mechanical threshing activity	0.161*** (0.047)	0.182*** (0.055)	−0.042 (0.048)	−0.043 (0.042)	−0.017 (0.031)	0.003 (0.028)	−0.024 (0.031)	−0.009 (0.031)				
	Mechanical transport	0.159*** (0.037)	0.041 (0.042)	0.058*** (0.015)	0.053*** (0.015)	−0.073*** (0.016)	−0.090*** (0.024)	−0.01 (0.019)	−0.018 (0.020)				
Storage	Storage time (in months)		0.006 (0.006)		−0.004 (0.003)		0.003 (0.004)		−0.002 (0.002)		−0.012 (0.008)		−0.003 (0.004)
	Storage: modern vs. traditional storage		−0.306*** (0.101)		−0.137 (0.110)		−0.012 (0.021)		−0.022* (0.013)		−0.058 (0.040)		−0.010 (0.048)
	Number of storage conservation activities[e]		0.068* (0.036)		0.003 (0.011)		−0.04 (0.031)		−0.031** (0.014)		0.010 (0.087)		0.044** (0.019)
Production problems and limitations to produce high quality (as perceived by the producer)	Climate	0.175*** (0.040)		0.072*** (0.019)		0.087*** (0.031)		0.008 (0.021)		0.048 (0.031)	0.009 (0.008)	0.042 (0.037)	0.031*** (0.009)
	Animals/rodents	0.125* (0.065)		−0.009 (0.015)		0.051 (0.042)		0.035** (0.016)					
	Pest	−0.006 (0.039)		0.007 (0.015)		0.011 (0.021)		0.040*** (0.011)		0.029 (0.026)	0.054*** (0.006)	0.027 (0.037)	0.013 (0.009)
	Knowledge									−0.023 (0.031)	−0.018 (0.039)	−0.041 (0.038)	0.010 (0.014)
	Disease	0.035 (0.077)		0.057*** (0.016)		−0.045 (0.028)		0.033** (0.014)					
	Soil quality									0.068*** (0.012)	0.072*** (0.007)	0.060*** (0.004)	0.010*** (0.001)
	Limited market access	−0.134*** (0.051)		0.010 (0.025)		0.045* (0.026)		0.015 (0.025)		0.046 (0.030)	0.011 (0.036)	0.064** (0.031)	0.027* (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 observations		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. For Guatemala, in the PROBIT model a significant number of observations are lost because of perfect prediction.

[a]Includes fertilizers, insecticides, herbicides and fungicides.

[b]Includes irrigation and "chapeo".

[c]Machine-driven production activities include cleaning, sowing, herbicide application, pest control, fertilizer application, and harvest.

[d]Refers to winnowing (sopla), threshing (desgrane), drying, putting in bags, and transport.

[e]Includes chemical fumigation, natural fumigation, and ventilation. The second column of each model reports results conditional on storage.

TABLE 7 Regression results of the probability of experiencing a loss and the total share lost: Teff value chain in Ethiopia

		Ethiopia			
		Probit		GLM	
Socioeconomic 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 activities	Storage dummy	−0.011		0.058	
		(0.183)		(0.154)	
	No. of post-harvest activities[c]	0.047	0.043	0.049	0.076***
		(0.058)	(0.043)	(0.030)	(0.027)

(Continues)

TABLE 7 (Continued)

		Ethiopia			
		Probit		**GLM**	
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 and 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 observations		1113	1094	1113	1094

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors in parenthesis clustered at the district level.

[a]Includes fertiliziers, insecticides, herbicides and fungicides.

[b]Includes mechanical herbicide and pesticide application, and plowing.

[c]Refers to cutting, drying, piling, threshing, winnowing, packaging and transport to piling, threshing and/or storage.

[d]Includes cleaning previous to storage and preparation of storage site. The second column of each model reports results conditional on storage.

TABLE 8 Regression results of the probability of experiencing a loss and the total share lost: Wheat value chain in China

		China		
		Probit	**GLM**	
Socioeconomic variables	Male producer	0.019 (0.056)	−0.025 (0.015)	−0.031 (0.025)
	Age of producer (in 10 years)	−0.003 (0.004)	0.000 (0.001)	−0.001 (0.001)
	Education: Primary (vs. no education)	−0.093 (0.112)	−0.027** (0.010)	−0.019 (0.026)
	Education: Middle school (vs. no education)	−0.125 (0.157)	−0.029** (0.012)	−0.022 (0.031)
	Education: Secondary or higher (vs. no education)	−0.039 (0.163)	−0.034** (0.015)	−0.023 (0.026)
	Experience in cultivation of wheat (in 10 years)	0.021 (0.027)	0.001 (0.007)	0.004 (0.015)
Market	Time to reach to closest city of 25,000 inhabitants (in 10 hours)	0.051 (0.161)	0.025 (0.038)	0.259*** (0.096)
Production	Log(total production wheat)	0.073** (0.030)		
	Improved seeds (dummy)	−0.016 (0.074)	−0.010 (0.019)	0.011 (0.019)
	Number of different inputs applied[a]	−0.006 (0.039)	0.002 (0.006)	−0.005 (0.011)
	Number of production activities done mechanically[b]	0.001 (0.072)	0.014* (0.008)	0.017* (0.010)
	Hired labor for harvest	0.112*** (0.032)	−0.008 (0.011)	0.005 (0.018)
Post-harvest activities	Storage dummy	0.336*** (0.098)	0.027*** (0.009)	
	No. of post-harvest activities[c]	−0.009 (0.045)	−0.014*** (0.005)	−0.020* (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)

(Continues)

TABLE 8 (Continued)

		China		
		Probit	**GLM**	
Production problems and limitations to produce high quality (as perceived by the producer)	Climate	−0.019 (0.071)	−0.006 (0.010)	
	Pest	0.291** (0.135)	0.071** (0.030)	
	Knowledge	0.050 (0.078)	0.002 (0.012)	
	Technology		0.005 (0.015)	
	Excess weed		0.058*** (0.019)	
	Crop lodging	−0.016 (0.102)	0.016 (0.015)	
	Market		0.030 (0.021)	
Location-fixed effects		Township	Township	Township
Agroecological zone dummies		Yes	Yes	Yes
No. of observations		115	911	441

Note: Conditioning on storage the PROBIT model does not converge. And also for the full sample significant number of observations are lost because of perfect prediction. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors in parentheses clustered at the county level.

[a]Includes fertilizers, insecticides, herbicides and fungicides.

[b]Includes mechanical land preparation, planting, fertilizer application, chemical application and harvesting.

[c]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, 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. In particular, the number of machine-driven activities, including cleaning, sowing, herbicide application, pest control, fertilizer application, and harvest, correlates with about 8% and 20%, respectively, points less likelihood of a loss in the bean value chain in Honduras and the teff value chain in Ethiopia, and with 3%–5% points reduced share of FL 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% points more likelihood of a loss), Guatemalan maize value chain and Chinese wheat value chain (respectively, about 3% and 15% 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% points less). Similarly, in Mozambique, mechanization reduces the likelihood of incurring a loss of maize (− 4% 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 in losses, with the correlation being significant in the potato value chains in Ecuador and Peru and the maize value chains in Guatemala and Honduras (between 4% and 8% points less likelihood of a loss and around 3% 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 it 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% points less likelihood of a loss), the potato value chain in Ecuador and the maize value chain in Mozambique (between 4% and 8% points less share of produce loss).

The lack of adequate storage techniques

This can lead to FL due to biotic factors (pests, 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. However, 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% points more likelihood of incurring any loss, and between 3% and 13% 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% 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% point less likelihood of incurring in a loss; and between 2% and 16% 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 are associated with 8%–18%, respectively, more likelihood of FL, and 3%–7% more share of produce loss). In addition, farmers mention pests, diseases, and rodents as major production problems.

DISCUSSION

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

Socioeconomic characteristics

Our results on the impact of gender on FL are contradictory. Similar findings have been reported by Chegere (2018), who found that being male is correlated with reduced losses in the sub-Saharan maize value chain. On the other hand, Folayan (2013) and Ngowi and Selejio (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 are 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 Ansahet al. (2017) find the same negative result for age. Basavaraja et al. (2007), Gebretsadik et al. (2019), Khatun and Rahman (2019), and Shee et al. (2019) find a negative association between education and losses. Kuranen-Joko and Liambee (2017) find a negative association between experience and losses.

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, Tetteh, & Donkoh 2017; Doki et al. 2019). Ngowi and Selejio (2019) and Shee et al. (2019) analyzed the maize and white-fleshed sweet potato value chains in Tanzania and Uganda and found that age is positively correlated with losses.

Market access

In line with most studies, our results find that transportation is positively associated with FL owing to the additional costs imposed on the farmer and complexities in transporting food commodities. Chegere (2018) finds that maize farmers in sub-Saharan Africa experience more losses if they transport maize themselves. Gebretsadik et al. (2019) found increased losses due to the distance between the farm and the residence as well as 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, Haji, & Tegegne 2019), maize in Tanzania (Ismail & 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 FL 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 FL. 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 and Rahman (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 & Selejio 2019), and our results on storage techniques confirm this finding by previous studies on FL. Previous studies have also found that losses significantly increased during longer storage periods (Aidoo, Danfoku, & Mensah 2014; Ismail & Changalima 2019). At the same time, the lack of modern storage facilities is positively correlated with losses (Folayan 2013; Maziku 2020; Paneru, Paudel, & Thapa 2018), demonstrating that improved storage infrastructure mitigates the risks of FL.

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 and 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, Schuster, & Torero 2020).

CONCLUSION

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

Our results show that socioeconomic 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 the 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, such as hoes, that accounted for an important share of losses in Peru's potato value chain. Likewise, in Mozambique, mechanization reduced losses of maize. The number of inputs applied follows 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 has a significant correlation with increased losses in five out of the seven countries. This indicates that the absence of markets represents a critical limitation for farmers. This directly supports the findings of previous studies that show the importance of better roads to reduce FL across the value chain.

While there are commonalities, FL is very context-specific. The heterogeneity suggests that policies aiming at the reduction and prevention of FL 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, as well as targeted training programs, can confirm the effectiveness of specific interventions on FL reduction.

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

Small holders, who produce only small surpluses, often face substantial market failures that contribute to FL. 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 FL 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.

ACKNOWLEDGMENTS

This work was undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets, which is led by IFPRI and funded by the CGIAR Fund Donors and under the Food Loss and Waste program of FAO.

ENDNOTES

[1] Ambler, De Brauw, and Godlonton (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, Mahajanashetti, and Udagatti (2007), Arah et al. (2016), and Kasso and Bekele (2016) identify high heat and moisture as the main causes of food loss in sub-Saharan Africa and India.

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

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

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

REFERENCES

Abdoulaye, Tahirou, John Herbert Ainembabazi, Corinne Alexander, Dieudonne Baributsa, Didier Kadjo, Bokar Moussa, Oluwatoba Omotilewa, Jacob Ricker-Gilbert, and Feleke Shiferaw (2016). *Post-Harvest Loss of Maize and Grain Legumes in Sub-Saharan Africa: Insights from Household Survey Data in Seven Countries*. Purdue Extension Agricultural Economics EC-807-W. Purdue University.

Adewumi, M, and Ayinde, O. 2009. Analysis of Post Harvest Losses Among Plantain/banana (Musa Spp.L.) Marketers in Lagos State, Nigeria. *Nigerian Journal of Agriculture, Food and Environment* 5(2-4): 35–38.

Ahmed, Umar Ijaz, Liu Ying, Khalid Mushtaq, and Muhammad Khalid Bashir. 2015. "An Econometric Estimation of Post Harvest Losses of Kinnow in Pakistan." *International Journal of Economics, Commerce and Management* 3(5): 373–383.

Aidoo, Robert, Rita A. Danfoku, and James Osei Mensah. 2014. "Determinants of Postharvest Losses in Tomato Production in the Offinso North District of Ghana." *Journal of Development and Agricultural Economics* 6: 338–344.

Ambler, Kate, Alan De Brauw, and Susan Godlonton. 2018. "Measuring Postharvest Losses at the Farm Level in Malawi." *Australian Journal of Agricultural and Resource Economics* 62(1): 139–160.

Ansah, Isaac Gershon Kodwo, Bright K.D. Tetteh, and Samuel A. Donkoh. 2017. "Determinants and Income Effect of Yam Postharvest Loss Management: Evidence from the Zabzugu District of Northern Ghana." *Food Security* 9: 611–620. https://doi.org/10.1007/s12571-017-0675-1

Arah, Isaac Kojo, Gerald K. Ahorbo, Etornam Kosi Anku, Ernest Kodzo Kumah, and Harrison Amaglo. 2016. "Postharvest Handling Practices and Treatment Methods for Tomato Handlers in Developing Countries: A Mini Review." *Advances in Agriculture* 2016: 6436945.

Baoua, Ibrahim, Laouali Amadou, B. Ousmane, Dieudonne Baributsa, and Larry Murdock. 2014. "PICS Bags for Post-Harvest Storage of Maize Grain in West Africa." *Journal of Stored Products Research* 58: 20–28.

Basavaraja, H., S.B. Mahajanashetti, and N.C. Udagatti. 2007. "Economic Analysis of Post-Harvest Losses in Food Grains in India: A Case Study of Karnataka." *Agricultural Economics Research Review* 20: 117–126.

Chegere, Martin Julius. 2018. "Post-Harvest Losses Reduction by Small-Scale Maize Farmers: The Role of Handling Practices." *Food Policy* 77: 103–115. https://doi.org/10.1016/j.foodpol.2018.05.001

Compton J.A.F., Magrath P.A., Addo S., Gbedevi S.R., Amekupe S., Agbo B., Penni H., Kumi S.P., Bokor G., Awuku M. (1997). The Influence of Insect Damage on the Market Value of Maize Grain: A Comparison of Two Research Methods. In: Proceedings of the Premier Colloque International: Lutte Contre les Déprédateurs des Denrées Stockées par les Agriculteurs en Afrique; Lome, Togo. 10–14 February 1997.

Compton, A.F. Julia, and John Sherington. 1999. "Rapid Assessment Methods for Stored Maize Cobs: Weight Losses Due to Insect Pests." *Journal of Stored Products Research.* 35(1): 77–87.

Delgado, Luciana, Monica Schuster, and Maximo Torero. 2017. *The Reality of Food Losses: A New Measurement Methodology*. Washington, DC: International Food Policy Research Institute (IFPRI). IFPRI Discussion Paper 1686. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131530.

Delgado, Luciana, Monica Schuster, and Maximo Torero. 2020. "Quantity and Quality Food Losses Across the Value Chain: A Comparative Analysis." *Food Policy*. 98: 101958. https://doi.org/10.1016/j.foodpol.2020.101958

Doki, Naomi Onyeje, Criscent Ike Eya, Mnena Franca Tughgba, Ogah Gabriel Akahi, and Agnes Ameh. 2019. "Determinants of Post-Harvest Losses of Orange in Selected Local Government Areas of Benue State." *International Journal of New Economics and Social Sciences* 2(10): 295–308. https://doi.org/10.5604/01.3001.0013.8106

Folayan, J.A. 2013. "Determinant of Post Harvest Losses of Maize in Akure North Local Government Area of Ondo State." *Journal of Sustainable Society* 2: 12–19.

Gebretsadik, Desale, Jema Haji, and Bosena Tegegne. 2019. "Sesame Post-Harvest Loss from Small-Scale Producers in Kafta Humera District, Ethiopia." *Journal of Development and Agricultural Economics* 11(2): 33–42.

Goldsmith, Peter D., Anamaria Gaudencio Martins, and Altair Dias de Mour. 2015. "The Economics of Post-Harvest Loss: A Case Study of the New Large Soybean-Maize Producers in Tropical Brazil." *Food Security* 7(4): 875–888.

Ismail, Ismail J., and Ismail A. Changalima. 2019. "Postharvest Losses in Maize: Determinants and Effects on Profitability of Processing Agribusiness Enterprises." *East African Journal of Social and Applied Sciences (EAJ-SAS)* 1(2): 203–211.

John, Adam. 2014. "Rodent Outbreaks and Rice Pre-Harvest Losses in Southeast Asia." *Food Security* 6(2): 249–260.

Kaminski, Jonathan, and Luc Christiaensen. 2014. "Post-Harvest Loss in Sub Saharan Africa: What Do Farmers Say?" *Global Food Security* 3: 149–158.

Kasso, Mohammed, and Afework Bekele. 2016. "Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia." *Journal of the Saudi Society of Agricultural Sciences* 17(1): 88–96.

Khatun, Mashrufah, and Muhammad Shahrukh Rahman. 2019. "Quantifying Postharvest Loss of Brinjal: A Farm Level Study in Bangladesh." *Journal of the Bangladesh Agricultural University* 17(4): 454–460. https://www.banglajol.info/index.php/JBAU/article/view/44605

Kikulwe, E.M., Okurut, S., Ajambo, S., Nowakunda, K., Stoian, D., and Naziri, D. 2018. Postharvest Losses and their Determinants: A Challenge to Creating a Sustainable Cooking Banana Value Chain in Uganda. *Sustainability* 10(7). https://doi.org/10.3390/su10072381.

Kumar, Deepak, and Prasanta Kalita. 2017. "Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries." *Foods* 6(1): 8. https://doi.org/10.3390/foods6010008

Kuranen-Joko, D.N., and D.H. Liambee. 2017. "Determinants of Postharvest Losses among Tomato Farmers in Gboko Local Governments Area of Benue State." *CARD International Journal of Agricultural Research and Food Production (IJARFP)* 2(4): 27–33.

Macheka, Lesley, Elisabeth J.H. Spelt, Evert-Jan Bakker, Jack G.A.J. van der Vorst, and Pieternel A. Luning. 2018. "Identification of Determinants of Postharvest Losses in Zimbabwean Tomato Supply Chains as Basis for Dedicated Interventions." *Food Control* 87: 135–144. https://doi.org/10.1016/j.foodcont.2017.12.017

Maziku, Petro. 2020. "Determinants for Post-Harvest Losses in Maize Production for Smallholder Farmers in Tanzania." *African Journal of Applied Research (AJAR)* 5(1): 1–11. https://doi.org/10.26437/ajar.05.01.2019.01

Ngowi, Elizabeth R., and Onesmo Selejio. 2019. "Post-harvest Loss and Adoption of Improved Post-harvest Storage Technologies by Smallholder Maize Farmers in Tanzania." *African Journal of Economic Review, African Journal of Economic Review* 7(1): 249–267.

Paneru, Ram B., Gokul Paudel, and Resham B. Thapa. 2018. "Determinants of Post-Harvest Maize Losses by Pests in Mid Hills of Nepal." *International Journal of Agriculture, Environment and Bioresearch* 3(1): 110–118.

Papke, Leslie E., and Jeffrey M. Wooldridge. 1996. "Econometric Methods for Fractional Response Variables with an Application to 401(k) Plan Participation Rates." *Journal of Applied Econometrics* 11(6): 619–632.

Papke, Leslie E., and Jeffrey M. Wooldridge. 2008. "Panel Data Methods for Fractional Response Variables with an Application to Test Pass Rates." *Journal of Econometrics* 145(1–2): 121–133.

Rosegrant, Mark W., Eduardo Magalhaes, Rowena A. Valmonte-Santos, and Daniel Mason-D'Croz. 2015. *Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth*. Food Security and Nutrition Assessment Paper. Copenhagen: Copenhagen Consensus Center. http://www.copenhagenconsensus.com/sites/default/files/food_security_nutrition_assessment_-_rosegrant_0.pdf.

Shee, Apurba, Sarah Mayanja, Eria Simba, Tanya Stathers, Aurelie Bechoff, and Ben Bennett. 2019. "Determinants of Postharvest Losses along Smallholder Producers Maize and Sweetpotato Value Chains: An Ordered Probit Analysis." *Food Security* 11: 1101–1120. https://doi.org/10.1007/s12571-019-00949-4

Tefera, Tadele. 2012. "Post-Harvest Losses in African Maize in the Face of Increasing Food Shortage." *Food Security* 4(2): 267–277.

Wooldridge, Jeffrey M. 2002. *Econometric Analysis of Cross Section and Panel Data*. 22. Cambridge, MA: MIT Press. https://mitpress.mit.edu/books/econometric-analysis-cross-section-and-panel-data.

How to cite this article: Delgado L, Schuster M, Torero M. On the origins of food loss. *Appl Econ Perspect Policy*. 2021;43:750–780. https://doi.org/10.1002/aepp.13156