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A review of global postharvest loss assessments in plant-based food crops: Recent findings and measurement gaps

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A B S T R A C T

Since the FAO "Global Food Losses and Food Waste" report in 2011 estimated one-third of all the food produced globally was being lost, researchers have been using many different methodologies to assess and measure postharvest food loss and waste. Several international research organizations and large-scale projects have included postharvest loss assessments in their project agendas, and hundreds of journal articles have been published. Estimated losses have been determined and reported in several different ways, including quantitative losses, qualitative losses, and economic losses. This review provides an overview of the measurement methods and findings of 268 postharvest loss assessment studies on plant-based crops from around the world.

Keywords: Postharvest losses, Food loss assessment, Quantitative losses, Qualitative losses

INTRODUCTION

The Food and Agricultural Organization of the United Nations estimates that globally about one-third of all the food produced is either lost or wasted before consumption. Even in the regions such as Sub-Saharan Africa (SSA), where food-insecurity is highly prevalent, approximately 20% of all the grains, 44% of roots and tubers, 52% of fruits and vegetables are lost between the harvest and consumption (FAO, 2011). This indicates an urgent need for greater attention towards reducing postharvest losses (PHL) in order to address the world's food security challenges and to determine what may be happening to these lost foods. Several international research organizations and large-scale projects have conducted in-house studies and fieldwork involving postharvest loss assessments. Early PHL studies include a project report by Genova et al. (2006) using a comprehensive survey to measure losses in vegetable crops on the farm, trader/collector, at wholesale and retail level for World Vegetable Center (earlier known as the Asian Vegetable Research and Development Center or AVRDC) in Cambodia. Similarly, the 'Appropriate Postharvest Technology Planning Project' measured PHLs on the farm, in the wholesale market and at the retail market for 26 horticultural crops in four countries in SSA and South Asia (WFLO 2010) and published a final report for a grant from the Bill and Melinda Gates Foundation. Individual researchers have published their findings on crop PHLs (often based on graduate research projects), and postharvest scientists have published a wide assortment of PHL studies via

international journals and conference proceedings. APHLIS utilized published PHL studies on staple food crops to estimate PHLs in Africa. Massive PHL studies were also conducted in SSA by A Green Alliance for Africa (AGRA, 2013 and 2014) on 11 staple crops in 11 countries (a total of 60 PHL studies), and by the Indian Council of Agricultural Research (ICAR) and Central Institute of Post-Harvest Engineering and Technology (CIPHET) (Nanda et al.., 2012) on 47 crops in every state in India. These comprehensive PHL studies were possible only by utilizing enormous amounts of time, trained personnel and funding.

This article is based on the literature reviews of a total of 268 individual PHL crop assessment studies described in 76 reports or articles published between 2006 and 2017, undertaken as a desk study by the World Food Logistics Organization (WFLO) and The Postharvest Education Foundation (PEF). It focusses on recent PHL studies, providing a brief description on different loss assessment methodologies being utilized, and an overview on the findings of the postharvest loss assessments of plant-based crops. Only those crop studies with well-described methodologies and which utilized samples or survey population of n ≤ 8 (either overall or for individual food supply chain (FSC) stages) were included in the review.

POSTHARVEST LOSS ASSESSMENT METHODOLOGIES

Globally, different postharvest food loss and waste assessment methodologies have been practised by various researchers, but the quality of the available information is often not good enough to identify appropriate solutions to reduce the losses, to adopt cost-effective practices and to make profitable postharvest agri-business investments. The current postharvest food loss assessment methodologies include ad hoc surveys, single-use data collection instruments, unstructured questionnaires, open ended interviews and focus group discussions. These ad hoc surveys imply the methods are created by the practitioner, without the application of any systematic approach or uniformity in scope or definitions. Every researcher develops their own data collection instruments for different target populations, and generally report their result as estimates or ranges. Ad hoc methods for PHL assessment can result in either high or low-quality data, depending on the level of expertise of the researchers who develop the surveys.

Sampling or direct measurements are less often utilized and are usually considered more accurate but highly time and resource consuming. Hybrid methods utilizing a combination of these methods were recently used to measure PHLs in a USAID Horticulture Innovation Lab funded project in Rwanda (Gill, 2017) and also during the PHL studies conducted in India, Rwanda and Nigeria during 2017 as a part of World Bank Group (WBG) funded pilot projects. A full review of PHL methods and measurements can be found in Kitinoja et al. (2018).

POSTHARVEST LOSS ASSESSMENT STUDIES

A list of 104 recent PHL assessment report documents published between 2006 – 2017 were gathered during the initial literature searches, out of which 27% (28) were dropped from the present desk study due to the poor data quality. Thirteen of these were eliminated because some of the important details such as sampling method for quantitative measurements, sample size, data collection process using qualitative methods, survey population size, or the analyses process used to calculate % losses were missing, which resulted in poor quality, missing or questionable data. For example, providing a list of key informants or site visits does not provide enough information to know how many data points were used to calculate the average PHLs reported for the crop overall or by FSC stage. Another 15 documents were eliminated because they did not actually measure or estimate PHLs. These latter studies may be titled "postharvest loss assessments" or include sections on postharvest losses, but they reported based only on published past studies (secondary data) or on survey respondent's general perceptions of losses (i.e. "50% of farmers reported experiencing postharvest losses").

The 76 PHL assessment report documents remaining in the pre-screened database each include one or more PHL crops, for a total of 268 PHL crop studies. These have been organized into a database and analyzed individually in terms of crop, country, data collection methods used, and the amounts and types of food losses reported overall or for one or more FSC stages. In the database, PHL data provided in an MS Excel worksheet for each FSC stage (such as farm, packhouse or processing) is given its own line item.

FINDINGS OF POSTHARVEST LOSS ASSESSMENTS

The methods used to measure quantitative losses included surveys via interviews and questionnaires (41%), direct measurements alone (7%) and mixed methods (37%). Only two studies used modelling, and five were based on a re-evaluation of existing PHL studies to conduct Life Cycle Assessments (LCAs).

The majority of the recent PHL studies were conducted in the regions of Sub-Saharan Africa and South Asia. Of the 268 crop studies reviewed, more than half (143) were conducted in Africa, focusing primarily on a few grains (52 studies, of which 30 were on maize). Only a few studies, mainly on perishable crops, have been conducted in Latin America/Caribbean (16) and Southeast Asia/Pacific (11). A single PHL study was conducted on tomatoes in Egypt, one study on apples in Lebanon (Middle East and North African (MENA) region), a few studies in Armenia (wheat, potato, tomato and apple) and one study on wheat were conducted in Iran (Europe/Central Asia region) (Table 1). Five crops (maize, soybeans, cassava, bananas and tomatoes) accounted for 42% of all PHL plant-based crop studies

Table 1: Regional locations of 268 PHL studies (2006-2017)

Type of crop	Africa	South Asia	MENA	SE Asia/ Asia - Pacific	Latin America/ Caribbean
Grains	52	20	0	0	3
Legumes/pulses	22	19	0	4	2
Roots/tubers	21	5	0	3	4
Fruits	14	20	1	0	3
Vegetables	34	28	1	8	4
Sub-total	143	88	2	15	16

PHL studies conducted in Africa included 27 different crops and 15 different countries, where Nigeria, Tanzania and Ghana each had 15 or more studies. Only one PHL study was reported on *teff* (*Eragrostis tef* (Zucc.) Trotter) in Ethiopia, and it was focused only on the farm level. No recent reports on studies were found for many French-speaking SSA countries including Togo, Cameroon or Chad, although FAO is known to be actively working on new field case studies in Cameroon, D.R. Congo and Burkina Faso. No recent PHL studies have been conducted on potatoes in Africa, despite the growing importance of potatoes as a staple food crop. South Asia PHL studies have been conducted on 38 different crops, mainly in India and Bangladesh (with 54 and 22 studies, respectively). No recent published studies were found for example, in Sri Lanka or Bhutan. Only two recent PHL studies have been conducted on maize in South Asia, despite its increasing production in many countries.

Many of the recent PHL studies focused on one FSC stage or provided only an overall figure for total PHL for the crop (11% of 268 studies). Fifty-three (53) PHL studies reported only on farm level losses (21.5%), six reported only on processing (2%) and five reported only on wholesale or retail marketing (2%). Although Affognon et al. (2017) reported that PHL studies in SSA focused mainly on storage, and 40 of the studies included in this review measured losses in storage, these more recent PHL studies did not focus only on storage.

Nearly all the studies provided data on quantitative losses, but only 75 (28%) of the reviewed 268 PHL studies included reports on measurements of qualitative data, and only 62 (23%) provided primary data on economic losses. PHL studies undertaken using Commodity System Assessment Methodology (CSAM) provided about one half of these, and reported on the quantitative, qualitative and economic losses for each crop. Only 5 PHL studies provided data on nutritional losses.

In the last decade several international research organizations and large-scale projects began including postharvest loss assessments in their project agendas, so it is expected that the available data on PHL findings will soon be expanding. For example, during 2013-14 the World Vegetable Center hired postharvest consultants to measure PHLs for vegetables in Ghana, Tanzania, Bangladesh, Nepal and Cambodia. In Tanzania, the Market Infrastructure, Value Addition and Rural Finance (MIVARF) Prime Minister's Office project conducted 9 PHL studies for staple crops, fruit and vegetables and postharvest training needs assessments in 9 districts as baseline studies for the first phase of the project. Recent PHL studies have been conducted by the FAO SAVE FOOD Initiative (on maize and bananas in Kenya; rice, chickpeas and mangoes in India); by World Food Logistics Organization (WFLO) and The Postharvest Education Foundation (PEF) for The Standing Committee for Economic and Commercial Cooperation of the Organization of the Islamic Cooperation (COMCEC) (maize, plantains and bananas in Uganda; cassava and sweetpotato in Nigeria; tomatoes in Egypt; groundnuts in Benin), and Agribusiness Associates Inc. (ABA) (green chillies, plantains, tomatoes and sweetpotatoes in Rwanda and tomatoes in Burkina Faso). National Resources Institute, University of Greenwich (NRI) conducted PHL studies on many crops and other foods for COMCEC (Tomlins et al., 2016). PHL studies on assorted food crops are in progress during 2017-18 in Rwanda, India and Nigeria (by ABA), Ethiopia, Burkina Faso, DR Congo, Timor West (by FAO SAVE FOOD), Ghana and Ethiopia (by Post Harvest Loss Innovation Lab (PHLIL) project), as well as in Australia (by Institute for Sustainable Futures, University of Technology, Sydney), the USA (by World Wildlife Fund (WWF), Global Cold Chain Alliance (GCCA) and University of California, Davis) and the European Union (by Food Use for Social Innovation by Optimising waste prevention Strategies (FUSIONS), The Waste and Resources Action Programme (WRAP) etc.). A few recently sponsored PHL studies are listed in Table 2.

Table 2: Recently sponsored PHL studies

Organization	No. of studies	Crops/Countries	Dates	Study authors, citations
Bill and Melinda Gates Foundation (BMGF)	26	Tomato, Mango, Eggplant, Cucurbits, Okra, Litchi (India); Orange, pineapples, peppers, amaranth, tomato (Benin); Tomato, pineapple, banana, amaranth (Rwanda); Okra, tomato, peppers, eggplant, cabbage, onion, mangoes, pineapple (Ghana)	2009-10	WFLO, 2010; Kitinoja, 2010; Kitinoja and AlHassan, 2012
ICAR and CIPHET	46	46 crops (India)	2010-12	Nanda et al., 2012
Alliance for a Green Revolution in Africa (AGRA)	60	Maize, rice, sorghum, millet, cowpea, groundnuts, soybean, pigeon pea, cassava, yam, sweetpotato (11	2012-14	AGRA, 2013 (Phase 1); AGRA, 2014 (Phase 2)

		countries in Sub-Saharan Africa)		
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	3	Rice, cassava and maize (Nigeria)	2013	GIZ, 2013, LCA studies based on PHL studies by Oguntade, 2013
World Vegetable Center (earlier AVRDC)	12	Tomatoes, leafy greens (Burkina Faso, Ghana, Kenya, Tanzania, Cambodia, Bangladesh)	2013-14	Appiah, 2013a,b; Dari, 2013; Owino, 2013
FAO	2	Maize, mango (Kenya)	2013-14	FAO, 2014
FAO	1	Pumpkin (Trinidad and Tobago)	2014	Mohammed, 2014
FAO	9	Mangoes, cassava, tomato (Trinidad and Tobago, Guyana, St. Lucia)	2014 -15	Mohammed et al. 2015 in ADMI
COMCEC	5	Cassava, sweet potato (Nigeria); Banana, maize (Uganda); Tomato (Egypt)	2015-16	Kitinoja et al. 2016 (based on CSAM studies by WFLO and PEF)
FAO	3	Rice, chickpeas, mango (India)	2015-16	FAO 2017a, b, c (Sathguru Management Consultants funded by Messe Düsseldorf) http://www.fao.org/save-food/projects/study-fl-india/en/
FAO	3	Maize, *teff*, millet (Ethiopia)	2015-17	In progress
FAO	1	Maize (Uganda)	2014-15	In press
FAO	3	Cooking banana, potato, cassava (Uganda)	2015-16	In press
FAO	3	Cowpea, maize, sorghum (Burkina Faso)	2015-17	In press
FAO	2	Maize, rice (DR Congo)	2015-17	In press
FAO and United Nations Industrial Development Organization (UNIDO)	6	2 crops each in Ethiopia, Malawi and East Timor	2015-17	In progress
International Food Policy Research Institute (IFPRI)	4	Beans, maize, potatoes, wheat (Ghana)	2016	In progress
FAO	1	Apples (Lebanon)	2016-17	Chahhal et al., 2017
FAO	2	Rice (Myanmar and Laos)	2017	In progress
Horticulture Innovation Lab	4	Tomatoes, green chillies, cooking bananas, orange flesh sweet potatoes (Rwanda)	2016-17	Chahine-Tsouvalakis et al., 2017; Musanase and Kitinoja, 2017; Rwubatse and Kitinoja, 2017 (CSAM studies for ABA)
World Bank	6	Tomatoes and Maize (Rwanda, Nigeria, India)	2017	Kitinoja and Dandago, 2017; Kitinoja and Odeyemi, 2017
Reduction of Post-Harvest Losses Innovation lab	4	Chickpeas, maize, sesame and wheat (Ethiopia)	2017	In progress
				"First of its kind" baseline survey on PHL in 4 regions of Ethiopia.

Quantity losses

Nearly all of the recent PHL studies included findings on measurements of quantitative data. Very few included information on standard deviations (for examples see Nanda et al.., 2012 and Ambler et al.., 2017). Only four PHL studies did not provide any quantitative data (Appiah 2013a, Appiah 2013b, Rwubatse and Kitinoja, 2017 and Emana et al., 2017). In the case of Rwubatse and Kitinoja (2017) in a PHL study of cooking bananas in Rwanda, 100% of the bananas were damaged by the time they reached the retail market, but none of them were discarded, so PHLs were measurable only in terms of quality losses and the related economic losses.

The PHL studies included in this desk study differed widely in scope (i.e. focusing either on the national level, a state or province, a city or FSC, or even a location-specific site such as a marketplace) and even the ranges of losses reported differed widely. Sometimes the PHL measurements were included in a much larger study, such as in India (Nanda et al.., 2012) which collected a wide range of data on pre-harvest and postharvest factors influencing food losses for multiple crops in each state of India. Naziri et al. (2014) used Value Chain Analysis (VCA) to compare cassava PHLs in 4 unique FSC stages (farm/harvesting, postharvest handling/transport, processing, and retail/consumption) in 4 countries (Ghana, Nigeria, Thailand and Vietnam). These FSC stages do not match with any of the stages considered by others in their loss assessment studies.

In Bangladesh, postharvest loss of fruits and vegetables ranged from 23.6 to 43.5% (Kamrul Hassan et al., 2010) with 350 to 400 data points collected per crop. The total loss was found to be the highest in jackfruit (43.5%) followed by pineapple (43.0%), papaya (39.9%) and cauliflower (34.4%). Mid-range losses were found for cucumber (27.1%), mango (27.4%), red amaranth (28.8%), eggplant (29.4%), okra (32.3%) and tomato (32.9%). Lower postharvest losses were observed in orange (23.6%), banana (24.6%) and litchi (24.9%). WFLO (2010) reported similar levels of PHLs for a wide range of fruits and vegetables in India, Ghana, Benin and Rwanda.

Nanda et al. (2012) measured PHLs in India for 37 grains, legumes/pulses, root/tuber, fruits and vegetable crops, using a combination of farmer and key informant surveys, observations and crop sampling during one full season (the remaining 10 crops included in their studies were oilseeds). Their report for ICAR used a pooling method to calculate average losses (% and SD) for the farm level, storage level and overall national level PHLs for each crop. The standard deviations are generally low, but those that are high provide a pointer to specific problems in the FSCs. For example, PHLs at banana harvest is reported as 1.33% with an SD of 8.59; indicating that while overall national banana farm PHLs are low, some of the farms are experiencing much higher losses (up to 10%).

The PHL studies conducted in India divided the population into marginal, small, medium and large size farms (Nanda et al. 2012). There are many examples of instances where marginal and small farmers are experiencing higher levels of PHLs than were medium and large for a particular crop, sometimes due to lack of access to tools and equipment such as threshers at the farm level or due to the use of traditional sacks as storage containers for grains or legumes.

The ranges of reported PHLs are usually very large. For grains and legumes/pulses the range of losses is 1 to 40%, varying based on the climate and season (wet or dry season), whether rain occurred during the period following harvesting, incidence of pests (for maize, especially whether or not the Larger Grain Borer (*Prostephanus truncatus* (Horn)) is present), and the utilization (or not) of improved processing and storage methods. The range of reported losses for various fruits, vegetables, root and tuber crops is even more enormous (from 0 to 80%) and this wide range is most likely due to the nature of the crop (whether it is highly perishable, moderately perishable or less perishable) as well as the under-reported contributing factors (such as initial disease incidence in the field, time from harvest, temperature during handling, weather conditions, type of

packages used, etc.). Losses of highly perishable crops when there are gluts can be enormous or even reach 100%, since the offered price for the produce may be so low that it does not make sense to harvest or transport the crop to market. This was the case in 2017 in India for tomatoes when the price fell to 30 INR for a 20 kg crate or the equivalent of US$ 0.025 per kg. When standard deviations for measured PHLs for perishable crops are reported, they tend to be very high. For example, Weinberger et al. (2008) reported that farmers (N=187) experienced average losses of 6.4±5.7% in Cambodia, Laos and Vietnam. In India, PHLs at banana harvest is reported as 1.33% with an SD of 8.59; (Nanda et al.., 2012). Kitinoja and AlHassan (2012) reported that the percent mechanical damage for individual samples of cabbage handled in very large sacks in Ghana (N=30) was measured at 55±20.1% (farm), 32±25.7% (wholesale), and 45±27.6% (retail market).

ICAR (CIPHET 2015) published a collection of food loss studies in India in book form. The national level food loss estimates for India in 2013–14 were higher for perishable crops than for staple crops:

- Cereals   4.65 to 5.99%
- Pulses   6.36 to 8.41%
- Oilseeds   3.08 to 9.96%
- Fruits   6.7 to 15.88%
- Vegetables   4.58 to 12.44%

A few of the PHL studies broke down the data and reported on findings by season. In Trinidad and Tobago, losses in pumpkin were reported at several FSC stages for the wet season and the dry season (Mohammed, 2014) (Table 3). The percentage of wet season PHLs were consistently higher, due to an increase in the incidence of cracks, internal breakdown and insect damage. Similar differences in findings were reported for mangoes in Benin (Vayssieres et al. 2008), with very high losses (70%) when fruit flies attack in the rainy season in June, compared to losses in early April (17%).

Table 3: Postharvest losses in pumpkin according to the type of market and season in Trinidad and Tobago

Market Type	Dry Season (% loss)	Wet Season (% loss)
Roadside	18.6	30.8
Farmers market	12.0	18.1
Wholesale	7.8	17.3
Mobile retail	15.1	27.9
Supermarket	22.3	29.9
Export	35.9	44.4
Average % marketing losses	**18.6**	**28.1**

The main factors that are most consistently related to higher levels of postharvest losses for perishable crops include rough handling, use of poor quality packages, high postharvest handling temperatures and delays in marketing (Kitinoja and AlHassan, 2012; WFLO, 2010; Kitinoja, 2010; Molla et al., 2010). Losses for highly perishable leafy green vegetables have been measured to be as high as 70 to 80% in West Africa, and losses in fruits to be 50 to 70%, especially during the rainy season. It is not unusual to find postharvest losses reported to average 20 to 50% during the period of time between harvesting and retail marketing, matching the figures used for UN FAO SAVE FOOD promotional info-graphics and posters. This amounts to an enormous waste of seeds and planting materials, land, energy, fertilizers, water, labour and other productive resources.

Quality losses

Only 28% of the PHL studies reviewed for this desk study included reports on measurements of qualitative data. Of the 268 recent PHL studies, 75 provided new primary data on qualitative losses, and many other included anecdotes or descriptions of qualitative problems that were observed by researchers or recalled by survey respondents. Approximately 55% of all the recent PHL studies that measured qualitative PHLs were done on perishable crops in Sub-Saharan Africa (Table 4).

Table 4: Regional locations of 75 Qualitative PHL studies (2006-2017)

Type of crop	Africa	South Asia	MENA	SE Asia/Pacific	Latin America/ Caribbean
Grains	6	1			2
Legumes/pulses	1				2
Roots/tubers	5			1	4
Fruits	9	3			3
Vegetables	20	12	1	2	3
Sub-total	**41**	**16**	**1**	**3**	**14**

Emana et al. (2017) reported on qualitative PHLs for tomato farmers, wholesalers and retailers in Ethiopia, missing the FSC stages of packers/traders and transporters. The qualitative loss data reported for the Caribbean region for cassava, mangoes and tomatoes were collected using the FAO field case studies methodology (FAO, 2015). Qualitative loss data was reported for many types of vegetables and fruits in Bangladesh (Ahmed, 2013) and for vegetable crops in Ghana (Appiah, 2013a, Appiah, 2013b), Kenya (Owino, 2013) and Rwanda (Rwubatse and Kitinoja, 2017; Musenase and Kitinoja, 2017). Qualitative data were collected at the farm, wholesale and retail market levels for a large number of different fruits and vegetable crops in India and SSA (WFLO, 2010) using the methodology of modified CSAM (LaGra et al., 2016).

Qualitative losses can be very high and result in economic losses. Measured damage to leafy greens transported in bunches tied in cloth reached 89% in Benin (WFLO, 2010). Green cooking bananas in Rwanda experience 98% damage by the time they reach the wholesale market and suffer from 100% damage at the retail market level, mainly due to rough handling and transport by bicycle load (Rwubatse and Kitinoja, 2017).

Very few of the recent PHL studies that have been conducted on grains, legumes/pulses and roots/tuber crops have measured or reported on qualitative PHLs.

Economic losses

Fewer recent PHL studies have included reports on measurements of economic data. Despite this being a relatively simple calculation based on farm gate prices or local market value per kg, few PHL studies provided economic loss data. Of the 268 PHL studies reviewed, only 62 (23%) provided primary data on economic losses. PHL studies undertaken using CSAM provided about one half of these (Table 5).

Table 5: Regional locations of 62 PHL studies reporting on economic data (2006-2017)

Type of crop	Africa	South Asia	MENA*	SE Asia/Pacific	Latin America/ Caribbean
Grains	6	2			2
Legumes/pulses	3	1			2
Roots/tubers	2	2			4
Fruits	4	10			
Vegetables	5	14	1	6	
Sub-total	**18**	**29**	**1**	**6**	**8**

*MENA = Middle East and North Africa

Kamrul Hassan et al. (2010) reported on overall economic losses per crop for fruits and vegetable in Bangladesh based on harvest prices, reporting losses in the local currency (Taka (1US$ ~ 85 Taka)). WFLO (2010) reported on economic losses at the retail level for amaranth (30%) and pineapple (33%) in Benin due to mechanical damage and weight losses. Sharma and Rathi (2013) provided data on economic losses for wheat and soybeans in India, reported losses in kg per acre and then calculated the change in market value. The 100% damage of cooking bananas in Rwanda resulted in a 20% loss in market value at the retail level (Rwubatse and Kitinoja, 2017).

An FAO (2015) study in the Caribbean calculated total estimated economic losses in cassava as they were measured as "unfit for sale" in Trinidad and Tobago (US $500,000) and Guyana (US $839,000). One study reported on economic losses for tomatoes and cauliflower per trader, wholesaler and retailer (ANSAB Nepal, 2015) requiring the market prices to be tracked over time. Gautam and Buntong (2015) reported on economic losses per hectare for vegetable crops in Cambodia. The amount of economic loss was estimated at approximately US $4,213 per ha for tomato and US $2,208 per ha for leafy mustard.

WFLO PHL studies for COMCEC reported on the range of annual farm level economic losses in Uganda (bananas, plantains, maize), Nigeria (cassava, sweet potatoes) and tomatoes in Egypt (Kitinoja et al., 2016), based on measured PHLs and the total volume of production. At a farm gate value of US$250-300 per metric tonnes (MT) and farm-level PHLs of 10 to 15%, the loss of economic value for Uganda's maize farmers is in the range of US$70 to $126 million per year. Taking a conservative estimate of on-farm losses of 15 to 20%, and an annual production volume of 8.5 million tonnes, Egyptian growers lose 1.28 to 2.17 million MT of tomatoes per year. At a market value of US $200 per MT, total economic losses for tomato farmers is approximately US$255 to $340 million in lost earning per year (Kitinoja et al., 2016).

Each of these PHL studies used different approaches for measuring, calculating and reporting on economic PHLs. Most of the PHL studies that reported on economic losses in Africa and Asia were conducted by researchers working with AVRDC or WFLO.

Other losses

Only 5 LCA studies reported on greenhouse gases (GHG) or carbon footprint due to lost food and 6 PHL studies included information on nutritional losses. Only a few studies reported on PHLs in terms of nutrition or calories (Kitinoja et al., 2016; Kitinoja and Dandago, 2017). Five PHL studies for COMCEC reported on calorie losses, including a study on maize in Uganda. The maize assessed during the field visits suffered extreme defects and decay on 10 to 45% of the crop. Maize losses at the farm level equals 280,000 to 420,000 tonnes per year, taking a conservative estimate of on-farm losses of 10 to 15% during harvesting and drying, and a total production of 2.8 metric tonnes per year. Maize has a food value of 3700 kilocalories per kg, which means that PHLs in food value is a minimum of 1.04 trillion kilocalories (Kitinoja et al., 2016). This amount could have fed 1.14 million persons for a full year at 2500 kcal/day or 3.4% of Uganda's population of 34 million.

Sweet potatoes have a food value of 860 kilocalories per kg. In Nigeria, the loss in food value due to farm level losses of only 2% or 69,000 tonnes of sweet potatoes is approximately 59.34 billion kilocalories that could have fed 65,000 persons for a full year at 2,500 kcal/day (Kitinoja et al., 2016). With a conservative estimate of cassava farm level losses on the order of 2 to 5% physical losses in Nigeria and a total production of 45 million tonnes, these losses equal 900,000 to 2,250,000 tonnes of cassava roots per year. Cassava has a food value of 1,600 kilocalories per kg. The losses in food value, at a minimum, equals approximately 14.4 trillion kilocalories. This could feed 15.78 million persons for a full year at 2,500 kcal/day (10% of Nigeria's population).

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

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

LCA studies based on Oguntade (2013) reported on cassava PHLs at the farm and processing levels, and for maize PHLs at the farm and retail level in Nigeria (GIZ, 2013). For cassava, 8.5% PHLs at the farm level was reported to be the equivalent of 3.19 million MT fresh roots, for a carbon footprint due to the losses of 0.28 million MT; and 12.1% PHLs at the processing level was reported to be the equivalent of 3.18 million MT of *gari* (a dry, crispy, creamy-white granular powder made from fermented cassava roots and a popular food in West Africa), for a carbon footprint due to the losses of 0.33 million MT. For maize, 3.5% PHLs at the farm level was reported to be the equivalent of 0.55 million MT of grain, for a carbon footprint due to the losses of 0.21 million MT; and 26.6% PHLs at the retail level was reported to be the equivalent of 1.94 million MT of grain, for a carbon footprint due to the losses of 0.82 million MT.

Overall PHLs for tomatoes (56%) and for green chillies (7%) based on ABA studies in Rwanda (Musanase and Kitinoja, 2017; Chahine-Tsouvalakis et al., 2017) were translated into GHG emissions due to losses and water use equivalents wasted due to losses (Daystar 2017). For tomatoes, GHG = 161 kg carbondioxide (CO_2) equivalents per MT, for a 24 Million kg CO_2 eq total due to losses. When scaled nationally, water use of 7,073 m3 per MT was wasted due to postharvest losses of tomatoes. For green chillies, a much smaller volume crop with lower overall PHLs, GHG = 12 kg CO_2 eq. per MT, for 53,000 kg CO_2 eq total emissions. When scaled nationally, 170 cubic meters of water is also lost due to postharvest losses of green chillies grown for export.

Each of the LCA and nutritional loss reports used a different approach and reporting details, such as losses of calories, nutrients (vitamins), GHG or carbon footprint. An example of an early attempt at calculating food loss/waste effects on natural resources can be found in Kummu et al. (2012). In general, according to FAO and Kummu et al. (2012) the production of fruits and field-grown vegetables generates relatively low GHG emissions. For F&V and grains, emissions are mainly due to the use of diesel and nitrogen fertilizers, as well as yield level. Potatoes and other root and tuber (R&T) crops are particularly efficient in the cultivation because of very high yield per unit area, so emissions of GHG per kg of R&T crops are low.

IDENTIFICATION OF GAPS

During the study, gaps were identified related to postharvest loss assessments, which need to be comprehensively addressed for each major postharvest issues/topic.

a) <u>Gaps in PHL Data</u>: Postharvest loss assessment gaps exist in terms of poor quality of available data, use of ad hoc data collection methods and lack of information on qualitative, economic or nutritional losses. Data is almost exclusively concentrated upon the measurement of % weight loss and related quantities of loss along the value chain, overlooking other relevant indicators like the economic value or the nutritional value of the loss. Ultimately, there is very little available

data that is similar enough to be gathered into a single global database and averaged for a crop or a time or a place, and it is nearly impossible to compare PHL data from the study to study.

b) <u>Gaps in terms of Value Chain Analysis of PHL</u>: Very few PHL studies follow a specific crop from harvest and along the food supply chain, measuring losses at each point over time, making it difficult to sum PHLs for the entire food supply chain. Instead, most PHL studies report on estimates of overall losses, or have focused on only one or two stages of the postharvest chain, for example on the farm, or during processing or marketing; newer PHL studies provide data at critical loss points or at specific value chain points, and do not gather data to calculate a total PHL level. Most studies have not been undertaken within the framework of integrated national statistical programs, but rather with donor-funded loss reduction projects taking place only in certain parts of the concerned countries or focused on individual companies or specific target groups.

c) <u>Gaps in postharvest loss assessment capacity</u>: There are gaps in postharvest loss assessment skills and experience and in postharvest practitioner technical knowledge and skills that are required to apply existing methods for postharvest loss assessments. Capacity building in this regard has been hindered by a lack of a standardized methodology, data collection practices and reporting protocols. There are also gaps in access for users to learning platforms, innovations and interventions (postharvest education, learning platforms, ICT, knowledge repositories, online libraries, etc.).

DATABASE OF COMPILED STUDIES FOR IMPROVING FUTURE POSTHARVEST LOSS ASSESSMENTS

Databases 1 provides details on the data collection methods used in the PHL studies that are included in the screened database. Database 2 provides the findings on PHL levels and types of losses for all 268 PHL studies. These databases are even provided as supplementary files along with this review, for researchers to utilize as baseline data, comparative data, or as examples to develop new studies that fill the reported PHL data gaps.

Database 1: PEF 2018 PHL Assessment Methods and Annotated Reference Database https://www.dropbox.com/s/el93vcurlzh5sjv/Database%201%20%20PEF%202018%20Annotated%20PHL%20studies%20reference%20list%20A%20to%20Z.xlsx?dl=0

Database 2: PEF 2018 PHL Studies Findings Database

https://www.dropbox.com/s/j3etj2vhj7tjoi8/Database%202%20PEF%202018%20PHL%20Findings%20268%20studies.xlsx?dl=0

CONCLUSIONS

In the last decade, the global attention towards reduction of postharvest food loss and waste has increased considerably, while several national and international projects and organizations have included postharvest loss assessments in their agendas. Different PHL assessment methodologies including interviews, sampling, and hybrid methods were adapted by various workers around the world, but most were ad hoc, designed by an individual researcher and used only once or twice. Many studies considered for the review were missing some of the important details such as sampling method for quantitative measurements, size of the sample, process of data collection, survey population size, and analysis method to estimate the losses. Of the 268 PHL crop studies included in the review, interviews and questionnaires are the most commonly used method to measure quantitative losses, while direct measurements, which can be more time consuming and costly, were less

popular. More than half of the recent PHL studies were carried out in South Asian and SSA regions. PHL studies conducted in different African nations included 27 different crops compared to 38 different crops in South Asia, mainly in India and Bangladesh. Most of the PHL studies provided quantitative losses data, while few included reports on qualitative and economic loss measurements.

Reporting postharvest losses is a complex phenomenon and the extent of losses reported may differ depending upon the region selected and the consumer acceptance of the product in that region. For example, during PHL studies in Rwanda it was observed that the cooking bananas were completely damaged (100%) by the time they reached retail market but still none of them were discarded. In such cases, the quantitative losses recorded is close to zero, but at same time there are considerable quality losses (which may become nutritional losses or food safety issues) and economic losses (20%). The very wide range of the extent of reported losses from 0 to 80 % in cereals, fruits, vegetables, root and tuber depends upon many factors such as the physiology of different crops, disease incidence, time of harvest, temperature during handling, weather conditions, packaging materials used, duration of handling or storage, etc. Some of the studies that reported PHL percentages or weights with standard deviations, found that higher standard deviation values indicate that overall PHL might be relatively low but that farms in some locations experienced much higher losses.

Fewer studies reported the qualitative losses data and most of these studies were done on perishable crops in SSA regions. Very few recent studies have been reported on qualitative losses of cereals, legumes and root/tuber crops. PHL in terms of economic losses were rarely reported despite involving a relatively simple calculation based on local market values. Some of the studies also represented PHL in terms of nutritional losses or carbon footprint due to losses, but these were very few in number.

Poor quality of available data is one of the crucial gaps identified related to postharvest loss assessments. Most of the PHL studies reviewed focused only on one or two stages of the value chain, making it difficult to sum up postharvest losses along the entire food supply chain. Other gaps in postharvest assessment include the lack of standardized methodologies and reporting protocols, lack of access to learning platforms for PHL measurement, and the lack of sufficient postharvest loss assessment skills and experience.

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