Reducing food loss in agricultural development projects through value chain efficiency

Working Paper No. 204

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Julie Nash
Olivia Peña
Gillian Galford
Noel Gurwick
Gillian Pirolli
Julianna White
Eva Wollenberg

USAID FROM THE AMERICAN PEOPLE

CGIAR

RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security

CCAFS

Working Paper

Reducing food loss in agricultural development projects through value chain efficiency

Working Paper No. 204

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Julie Nash
Olivia Peña
Gillian Galford
Noel Gurwick
Gillian Pirolli
Julianna White
Eva Wollenberg

Correct citation:
Nash J, Peña O, Galford G, Gurwick N, Pirolli G, White J, Wollenberg E. 2017. Reducing food loss in agricultural development projects through value chain efficiency. CCAFS Working Paper no. 204. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors.

Contact:
CCAFS Program Management Unit, Wageningen University and Research, Lumen building, Droevendaalsesteeg 3a, 6708 PB, Wageningen, The Netherlands. Email: ccafs@cgiar.org

Abstract

Food loss and waste (FLW) reduces the amount of food available for distribution and consumption, decreases food security, and increases the environmental burden of food production. Combating FLW addresses the key pillars of climate-smart agriculture for farmers by increasing productivity, promoting adaption to climate change, and mitigating greenhouse gas emissions. Although studies of interventions to reduce FLW exist, almost no research systematically investigates FLW interventions across value chains or in multiple countries, most likely due to challenges in collecting and synthesizing multi-country estimates. Our research team investigated changes in FLW in projects supported by the United States Government's global hunger and food security initiative: Feed the Future. This provided a unique opportunity to conduct ex-ante estimates of the impacts of interventions across 20 value chains in 12 countries based on interviews with United States Agency for International Development (USAID) and project staff. We provide specific examples of interventions used in each value chain and country context. The results provide an evidence base of interventions that successfully decreased FLW at multiple points along the food value chain, from upstream producer-dominated stages to downstream consumer-dominated stages. Results also show that no single FLW solution or intervention works across agriculture sub-sectors, value chain stages, and countries. Amongst the sub-sectors studied, results showed that FLW interventions directed at extensive dairy systems could provide meaningful greenhouse mitigation. In the dairy supply chain, FLW estimates ranged from 5-50% in the business-as-usual approach and declined 4-10% as a result of intervention.

Keywords

Food loss and waste; Postharvest loss; Value chains; Climate change mitigation; USAID

About the authors

Dr. Julie Nash was, at the time this work was done, a scientist in low emissions agricultural development with CCAFS and a research associate at the at the Gund Institute for Environment and the Rubenstein School of Natural Resources at the University of Vermont. She is now a Senior Manager in Food and Capital Markets for Ceres.

Olivia Peña is a Research Intern for CCAFS and a Food Systems masters student at the University of Vermont.

Dr. Gillian Galford is a Research Assistant Professor at the Gund Institute for Environment and the Rubenstein School of Environment and Natural Resources at the University of Vermont.

Dr. Noel Gurwick is a Sustainable Landscapes and Climate Change Advisor in the Office of Global Climate Change at the U.S. Agency for International Development.

Gillian Pirolli is an independent consultant and data analyst.

Julianna White is Program Manager for Low Emissions Development at CCAFS based at the Gund Institute for Environment and Rubenstein School of Environment and Natural Resources, University of Vermont.

Dr. Eva Wollenberg is the Flagship Leader for Low Emissions Development at CCAFS and a Research Professor at the Gund Institute for Environment and Rubenstein School of Environment and Natural Resources, University of Vermont.

Acknowledgements

Thank you to the USAID staff and implementing partners who provided data, information, and time. This work is the result of a collaboration among the United States Agency for International Development (USAID), the Food and Agriculture Organization of the United Nations (FAO), and CCAFS, which is a strategic partnership of CGIAR and Future Earth. This research was made possible by the support of USAID and CCAFS donors. For more information, please visit https://ccafs.cgiar.org/donors.

Contents

Introduction

A grand challenge of the 21st century is increasing economic growth across the globe while dramatically decreasing greenhouse gas (GHG) emissions – decoupling two trends that have often moved in concert in the past. Along with economic growth and climate change, there is an urgent need to provide food security for a growing population. Sustainable agricultural development aims to address these challenges – and others – by increasing agricultural and economic productivity, helping farmers and herders adapt to climate change and variability, and decreasing greenhouse gas (GHG) emissions from agricultural production and land use change. Collectively, these three areas – production, adaptation and mitigation-- are the pillars of climate-smart agriculture. These emissions contribute nearly a quarter of GHG emissions globally (Smith et al. 2014), and therefore need to play a part in overall emission reductions.

Reducing food loss (which commonly refers to a decrease in edible food early in the supply chain) and waste (which generally occurs at retail and consumer stages) addresses the grand challenges of future food security and climate change by simultaneously addressing productivity and GHG emission reductions. Roughly one-third of food is lost or wasted worldwide, representing large, potentially avoidable losses of land, water, and energy (Gustavsson et al. 2011). Reduced food loss or waste (FLW) would result in more food for sale, distribution and consumption, increasing food security, while reducing the demand for increased food production with its attendant environmental burden (Hiç et al. 2016). In addition, interventions designed to reduce FLW can improve small-scale producers' resilience to climate change and variability, which generally impacts global food systems positively. Reducing FLW increases food availability at the farm gate, leading to a higher percentage of food sold on the market and higher incomes (Stathers, Lamboll, & Mvumi. 2013).

FLW occurs at multiple points along the food value chain, from upstream producer-dominated stages to downstream consumer-dominated stages (Porter & Reay 2015). Both developing and industrialized countries experience large amounts of FLW, although the point of loss or waste varies with production practices, value chain, and state of value chain development. Developing countries experience food loss due to limited infrastructure and little available capital in the food value chain (Beddington et al. 2012, Hodges 2012, Rosegrant et al. 2016).

Most research in developing countries has considered mainly on-farm losses rather than losses further down the supply chain, for example during processing, storage, and transportation (Sheahan & Barrett 2016). More industrialized countries have more food waste due to lack of coordination among value chain actors and higher quality standards that cause rejection of food items for minor imperfections (Gustavsson et al. 2011).

Definitions of postharvest loss (PHL) and food loss and waste vary among sectors. FAO (2011) defines PHL of agricultural products as any product loss caused by physical spilling and/or degradation during handling, storage, and transportation from the farm to distribution. FAO distinguishes food loss and food waste by the phase where the loss or waste occurs, e.g., food loss occurs pre-consumer and food waste occurs at the consumer phase. Porter et al. (2015) modified the FAO definitions to distinguish between "lost food" and "wasted food" in order to separate the political term of "waste." The Global Knowledge Initiative (2014) melds food waste and loss into the term "food wastage." Sims et al. (2015) states, "wastage occurs mostly during agricultural production, PHL handling and storage, and consumption phases." Often, distinguishing between loss and waste reflects "fundamentally different perspectives, underlying objectives, and policy concerns" (HLPE 2014). In this paper, we follow the most common definitions in FLW literature; food loss occurs prior to food reaching the consumer, and food waste occurs at the consumer level. We refer to food loss and food waste collectively as FLW throughout this document.

Estimating FLW is a challenging task. Many global-scale estimates of FLW are derived from a small assortment of primary sources, often including FAO's balance sheets, largely because it is challenging to collect and synthesize FLW information across countries (Affognon et al. 2015, Rosegrant et al. 2016). These challenges with large-scale synthesis stem from the fact that FWL data originate from diverse sources collected at varying geographic scales (global, regional, local) and along different parts of the value chain (production, processing, storage) (Sheahan & Barrett 2016). Even regional estimates often include a limited number of countries; for example, a PHL meta-analysis by Affognon et al. (2015) evaluates interventions in several categories (grains, vegetables, fruits, rootstocks, and animal products), and in six African countries. Overall, limited availability of comparable data sets has resulted in few research studies that collect FLW data on multiple crops across many countries.

Investigating FLW in development projects provides the opportunity to systematically study FLW-reduction interventions (hereafter referred to as FLW interventions) in multiple value chains and countries. This report focuses on FLW interventions in 13 USAID Feed the Future agricultural development projects in 12 countries in Africa, Asia, and Latin America and the Caribbean. The 13 projects promoted value chain links among input suppliers, producers, processors, and markets, and included 18 different crops and 2 dairy systems. We analyze a full spectrum of interventions that can reduce FLW falling in five categories: input choice (pre-harvest); practices used for harvesting, processing, and storage; and options for transport to retail.

This paper describes the scope of FLW interventions and estimates the extent to which they reduce greenhouse gas (GHG) emissions in diverse systems. Reducing FLW can contribute to GHG mitigation via two pathways. First, reducing loss increases the efficiency of the food supply chain, resulting in increased efficiency of GHG emissions per unit of food produced (emission intensity). Total emissions decline when farmers combine FLW reduction with (a) reducing emissions in the supply chain through improved practices or technologies (such as more efficient energy use), or (b) reducing agricultural production, a strategy that is relevant where farmers are constrained by high input costs (e.g. fertilizer, livestock feed, electricity) or face limited markets for their products (Kendall, 2000). Lipinski et al. (2013) estimate that higher production needs due to FLW generate 3,300-5,600 million Mt of unnecessary greenhouse gas emissions annually. This theory is relevant when producers are financially strained by the cost of inputs or cannot produce sufficient amounts of food after FLW occurs. Second, decomposition of lost or wasted food releases methane, nitrous oxide, and CO2, so decreasing FLW may reduce emissions from this route as well. However, even if consumed, food decomposes in humans and ultimately produces carbon dioxide, methane and indirectly nitrous oxide, so the potential to reduce GHG emissions from decomposition of FLW is salient mainly when FLW decomposes in oxygen-poor conditions, as in a landfill, where methane emissions are much higher than they would be if food were consumed. This report considers GHG reductions resulting only from efficiency in the food supply chain the first of these two paths.

Background

FLW stages in the food value chain

Food loss and waste at each stage of the value chain leaves less food available in each subsequent stage, causing large cumulative reductions in food available for consumption. This cascade also affects actors all along the value chain (Figure 1). For example, losses at harvest leave fewer products for processors. All stakeholders in the value chain therefore share a profit motive to minimize loss (Sheahan & Barrett 2016).

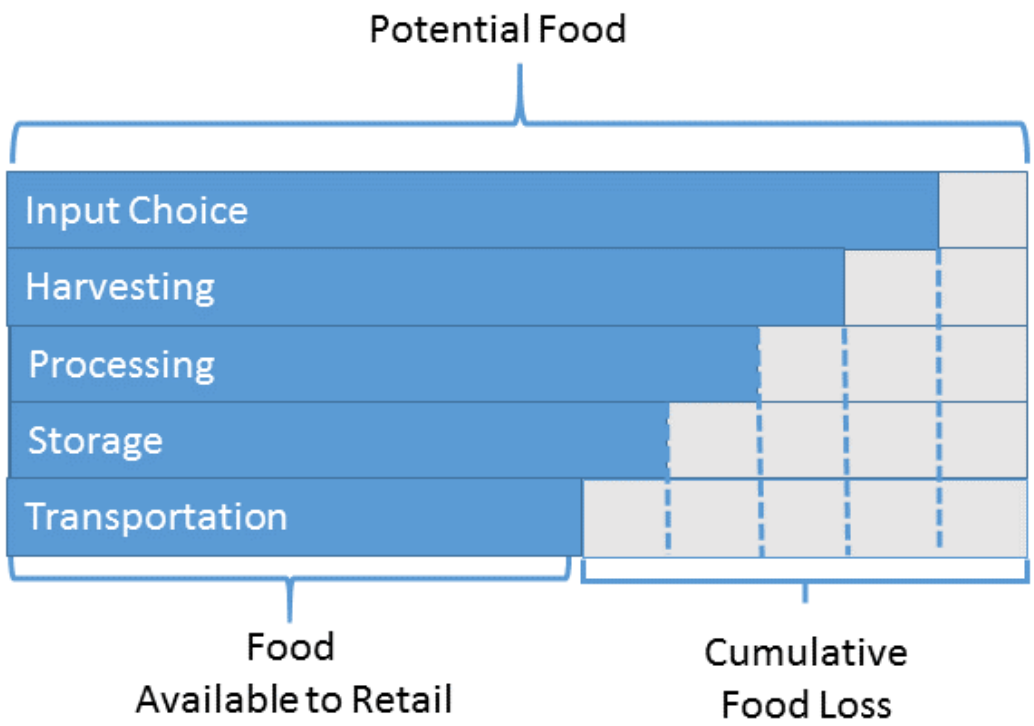


Figure 1. *Cumulative effects of FLW in food value chains.*
Food available for retail distribution is the potential food minus the cumulative effect of food loss at each stage of the chain. Losses vary by product and value chain step.

Potential interventions can be prioritized by considering the size of FLW or emissions and the scale of implementation of interventions. The potential for mitigation is high if considering any of these factors; priorities would occur when there are high values for all factors. This approach matches the value chain approach employed by USAID.

This paper focuses on input choice (pre-harvest), harvesting, processing, storage, and transportation to market, as these are focal areas for food security and FLW interventions in the programs studied. Descriptions of the stages and examples of interventions are summarized in Figure 2. A narrative description follows.

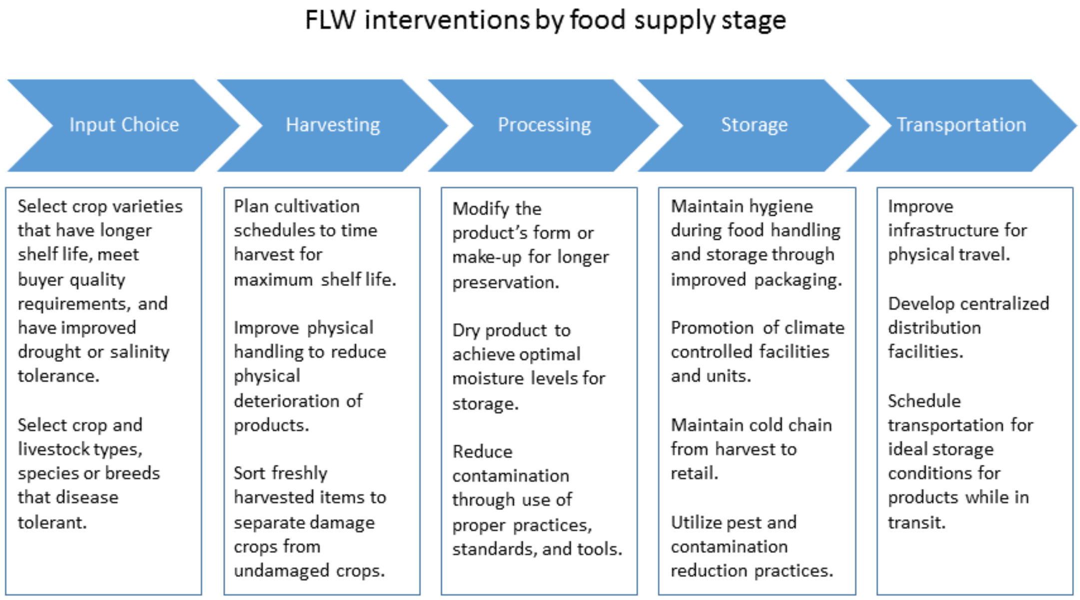


Figure 2. *Examples of FLW interventions at five stages in the food supply chain*

Input choice. Interventions influencing producers' input choices strive to promote pre-harvesting decisions that lead to a reduction in losses at later stages (HLPE 2014). Farmers have many means of affecting production through input choice. Producers may reduce food loss by selecting seed varieties that: a) result in products that last longer after harvest (Pessu et al. 2011, Prusky 2011); b) yield a marketable product even under challenging growing conditions, including climate change (e.g. species or varieties that tolerate heat, drought or salinity); or c) attain or retain desirable quality attributes that increase the likelihood of consumption (e.g., color, texture, taste) (HLPE 2014). In animal production, input breed selection and genetic considerations can reduce incidence of disease or malformations, reducing food loss (Stear et al. 2001). Providing shade could also reduce heat stress or nutrient-rich food sources are also ways to affect animal health and productivity through input choices.

Harvesting. Carefully designed planting and harvesting calendars can help farmers time harvest to maximize shelf life, such as using ambient conditions to reduce moisture in grains before harvest (Prusky 2011, Paulsen et al. 2015). Improved physical handling during harvest can reduce losses due to deterioration of produce. For example, mangos harvested with cutting poles reduced the frequency of latex burns on fruits (Bonicet 2013). Training field workers to reduce mechanical damages during harvest also reduces losses (Prusky 2011, Paulsen et al. 2015), so Paulsen et al. (2015) recommend that handlers attend seminars to hone their skills before operating mechanized equipment and processers. In the livestock sector, improved training of dairy farmers in milk handling practices reduces product contamination and microbial spoilage (Lore et al. 2005). Sorting recently harvested produce to separate damaged crops from undamaged crops also reduces loss (Pessu et al. 2011). Humidity gauges indicate optimal moisture levels for produce at harvesting time and can thus reduce the incidence of mold and rot (Hell et al. 2010).

Processing. Processing includes transforming a product into a longer-lasting form (Lore et al. 2005), for example by converting milk to value-added products such as butter, yogurt, and cheese or drying produce to achieve moisture levels ideal for storage (Hell et al. 2010). Lore et al. (2015) explain the importance of training handlers in milk hygiene. For rice and beans, processing improvements include proper drying in preparation for storage (Rani et al. 2013). Reducing contamination during processing (Karlovsky et al., 2016) also reduces spoilage.

Storage. The location and physical micro-environment of products during storage impacts FLW. Physical containers, such as plastic crates, off-ground basins, silos, and triple bags, reduce FLW by limiting contamination, product deterioration, and predation by pests (De Groote et al. 2013, Lipinski et al. 2013, Baoua et al. 2014). In many areas, storage conditions are poor, including the absence of appropriate refrigeration and cooling structures for dairy and meat products (Lore et al. 2005). Maintenance of the cold chain from harvest to retail reduces spoilage of fruits and vegetables (Prusky, 2011). Innovative cooling mechanisms, such as low- to no-energy refrigerators, require less mechanical input (Lipinski et al., 2013) and so should be considered in development initiatives. Finally, packaging improvements can reduce FLW by maintaining product quality through storage and shipment to retail (Opara & Mditshwa, 2013). Proper packaging can also contribute to hygiene during food handling and promote longer shelf-life of food products (Opara & Mditshwa, 2013).

Transportation. FLW in the transport or shipping of products between PHL phases, and to retail, can be reduced through local infrastructure improvements such as feeder roads that connect markets and agricultural centers (Beddington et al. 2012, Bahadur et al. 2016). Another promising option is collection centers, centralized hubs where products or commodities can be consolidated for processors to pick up before retail (Lore et al. 2005). Modifying transportation procedures, such as hauling during the cool part of the day, can also reduce losses (Pessu et al. 2011).

FLW and greenhouse gas mitigation

Reducing FLW is an under-used approach for combating climate change. A literature review conducted in late 2016 revealed only 23 studies that addressed GHG emissions resulting from either food loss or food waste or both. Some studies provided global estimates of all FLW, and others made regional- or country-level estimates for specific value chain phases (See Appendix 1). Only one article presented primary FLW data; the other 22 papers relied on pre-existing studies or data. The single paper presenting primary data focused on two crops in one region in Brazil (Goldsmith et al. 2015). Seven of the eight studies with global FLW-driven GHG emission estimates relied on FAO country estimates, although the reworking and application of the data varied.

Methods

Project description

USAID's Office of Global Climate Change engaged CCAFS to assess opportunities and approaches for low emission development related to agriculture and food security. CCAFS worked with the FAO, the USAID Feed the Future program, USAID country missions, and USAID implementing partners. The team examined projects within the Feed the Future initiative that aims to boost farmer food security and nutrition. Researchers selected 24 projects with high potential for agricultural GHG mitigation based on expert judgment of the scale of anticipated emissions reductions possible. Researchers from the FAO, USAID, and CCAFS conducted face-to-face or telephone interviews with project managers regarding project-driven activities, including their impacts on food security, productivity, and GHG emissions. Thirteen of the 24 projects engaged in FLW-related interventions and are thus included in this working paper.

FLW interventions and estimates

The research team gathered estimates of FLW (or PHL since FLW and PHL were used interchangeably in some projects) from implementing partners during semi-structured interviews; the team did not make primary measurements. Individuals interviewed had significant experience working in the targeted value chains in these countries.

USAID defines food losses as occurring from field to market (MacCartee 2013). When asked, interviewees emphasized the USAID definition, which includes production (harvest and input selection), processing, and storage losses. The research team asked managers to estimate the percentage of FLW ex ante with and without project interventions and to describe the practices involved in securing FLW reductions. In most instances, FLW data was collected through qualitative surveys and interviews and had already been shared in official project reporting to USAID. In a few instances, project managers developed quantitative surveys to measure reductions in FLW.

In addition to conducting interviews, the project team reviewed and coded project documents, including work plans, websites, and annual and quarterly monitoring reports. This content analysis provided information on the breadth of FLW interventions and enabled identification of key terms for interventions based on phases, for example "threshing" is a processing intervention, and "covered silo" is a storage intervention.

The team calculated the per unit impact of FLW interventions as the change in FLW with interventions compared to business-as-usual (BAU) (Equation 1). The total FLW in both cases is a function of the total yield and the percentage FLW, given the estimated amount of product lost per ha or per head of livestock per year.

Equation 1:

$$\boldsymbol{FLW\ impact = (FLW_{Intervention}\ x\ yield_{Intervention}) - (FLW_{BAU}\ x\ yield_{BAU})}$$

Greenhouse gas emission estimates

Implementing partners of selected projects provided information, data, and estimates on adoption rates of improved agricultural practices and annual yields. The research team then estimated GHG emissions and carbon sequestration associated with the BAU and improved agricultural practices using the Ex-Ante carbon balance tool (EX-ACT) developed by FAO using tier 1 guidelines (Bernoux et al. 2010, Bockel et al. 2013, Grewer et al. 2016), or using other methods if they were more appropriate for that value chain (Grewer et al. 2016). Uncertainties associated with these estimates can range from 30-50%; for nitrous oxide emissions from fertilizer use the uncertainty can be as high as 300%. Despite these uncertainties, EX-ACT represents the accepted state of the science and provides a comparable tool to other regions or studies. EX-ACT was selected based on its ability to account for a variety of GHGs, practices, and environments. Additional details on the method for deriving emission intensity and practice-based estimates can be found in Grewer et al. (2016). When accounting for the emission implications of FLW, our estimates only included the GHG impact of production of the lost or wasted food, not emissions resulting from its decomposition. Further, FLW studies do not lend themselves to assessing long-term sequestration of carbon. This work, and most work in FLW, does not account for the possibility of increased emissions introduced by new processing methods, storage, or transportation interventions.

This study surveyed the types of FLW interventions within selected projects to examine opportunities for low emissions development, and results reflect several methodological constraints. First, in most instances the estimates and intervention descriptions used are based on the expert judgment of the projects' implementing partners and were not independently verified. Second, the report reviewed only losses in the quantity of product – the physical decrease in product available, measured by weight or volume. Third, researchers did not provide a specific time horizon for storage to ensure uniformity of data. Finally, the study and interviews focused on climate change mitigation as a whole, the study focused on value chains with opportunities for significant GHG emission reductions (most often in the livestock, rice, and maize sectors) and carbon sequestration (perennials and agroforestry), rather than value chains with high FLW opportunities.

In addition, GHG estimation methods used in this paper did not account for the possibility of increased emissions resulting from new processing methods, storage, or transportation interventions, which could offset emission reductions. For instance, improvements in the dairy cold chain could increase GHG emissions due to increased electricity usage, or an established cold chain could encourage and promote increased dairy production. Changes in handling and packaging could improve hygiene during food handling and promote longer shelf-life of food products, but they also may lead to more waste. Finally, this research did not attempt to quantify the GHG implications of transportation interventions.

Results

Projects reporting reductions in FLW

The team identified 13 Feed the Future projects that had the potential for GHG emissions mitigation through FLW (Table 1).

Table 1. Projects studied with FLW interventions

Project name	Abbreviation	Agricultural products with potential for reduced FLW	Country
ACCESO	ACCESO	Maize, plantain, legumes (beans), vegetables (onions, potatoes), fruit (passion fruit)	Honduras
Agricultural Development and Value Chain Enhancement II	ADVANCE II	Maize, rice, legumes (soybeans)	Ghana
Agricultural Growth Program –Ag and Market	AGP-AMDe	Coffee, maize, sesame, wheat, legumes (chickpea)	Ethiopia
Better Life Alliance	BLA	Legumes (soybeans and groundnuts), maize, rice	Zambia
Camel Milk Project	Camel Milk	Dairy	Ethiopia
Chanje Lavi Plantè	Chanje	Legumes (beans), vegetables (plantain), maize, fruit (mangos), rice	Haiti
Commodity Production and Marketing	CPM	Legumes (beans), coffee, maize	Uganda
Food and Enterprise Development	FED	Rice, vegetables	Liberia
Helping Address Rural Vulnerabilities and Ecosystem Stability	HARVEST	Fish, rice, vegetables	Cambodia
Kenya Agriculture Value Chains Program	KAVES	Dairy, maize, fruit (passion fruit, mangos)	Kenya
Livestock for Improved Nutrition	LPIN	Dairy, meat	Bangladesh
Maximizing Agricultural Revenue and Key Enterprises in Targeted States II	MARKETS II	Fish, vegetables (cassava), rice, cocoa, sorghum, maize, legumes (soybeans)	Nigeria
Rwanda Dairy Competitiveness Project	RDCP	Dairy	Rwanda

These projects, located in 12 countries across Africa, Asia, and Latin America and the Caribbean (Figure 2), involved multiple crops and livestock production systems. FLW interventions were most common in maize and rice. One project, MARKETS II, included FLW interventions in six commodities (see Appendix 2).

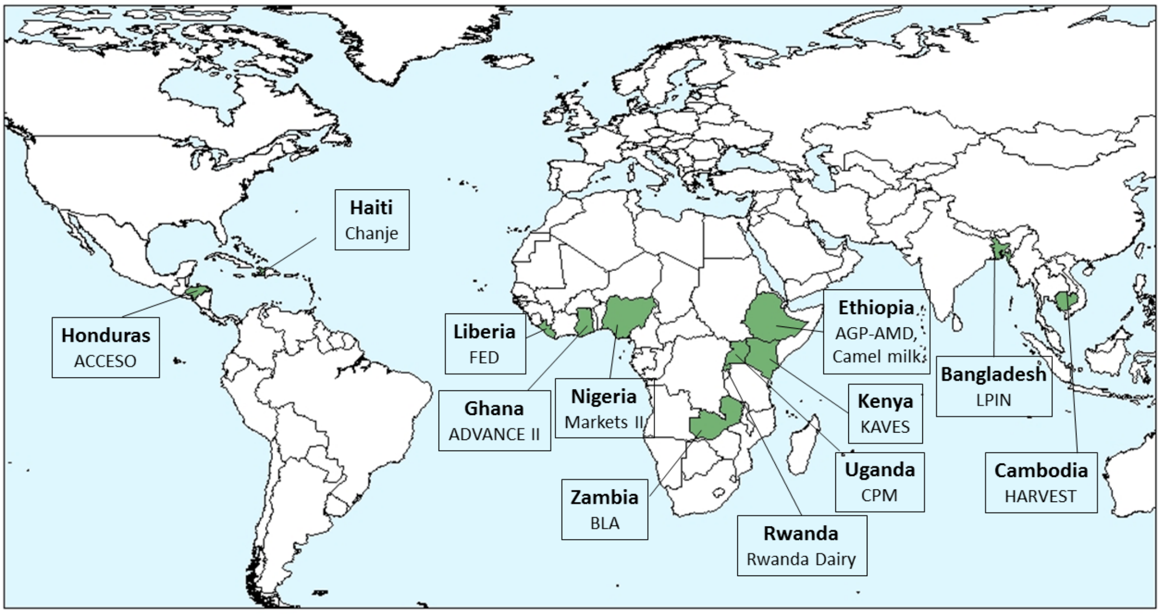


Figure 3. *Feed the Future projects reporting reductions in FLW*

FLW interventions

The 13 projects included FLW training or training plans for actors in the value chain as part of their interventions (Appendix 2). The most common interventions focused on storage and processing. Less common were input choice and harvesting. Many projects mentioned potential for improvements in transportation, but only a few described transportation interventions. Interventions in each stage are described below.

Input Choice. Approximately half of the projects documented interventions to reduce food loss through improved input choice, most often of crop varieties that have a longer shelf life or higher disease resistance. Changes in input choice for livestock focused on selecting breeds with disease resistance, acquiring healthy animals, and/or choosing animals that could be slaughtered at a younger age. Examples of activities to inform interventions on inputs included:

- ACCESO (Honduras) studied twelve varieties of yellow onions to determine which variety had the longest shelf life and exhibited most resistance to diseases.
- LPIN (Bangladesh) hosted training events for livestock producers on techniques for selecting fit, healthy animals for slaughter.

- MARKETS II (Nigeria) promoted farmer selection of cocoa varieties that have better disease and pest resistance qualities and characteristics desired by buyers.
- RDCP (Rwanda) identified livestock genetic qualities and breeding decisions that promote productive and healthy animals. This intervention also considered financial sustainability, accessibility of knowledge and practices, and feasibility of implementing decisions.

Harvesting. Projects that mentioned harvesting interventions with FLW implications identified practices that addressed environmental conditions during harvesting, such as reducing moisture that leads to mold and decay, or promoting harvesting techniques to preserve product quality. Some activities encouraged sorting recently harvested items to remove damaged produce to reduce spreading rot. A few projects emphasized measures to reduce pests or contamination during harvest. Examples of harvesting interventions to reduce food loss included:

- ACCESO (Honduras) promoted use of a planting and harvesting calendar to help farmers time their harvest to maximize revenue and shelf life.
- Chanje (Haiti) promoted use of cutting poles during harvesting to reduce damage to mangos from latex burns on the fruits, thus decreasing the market rejection rate.
- MARKETS II (Nigeria) supported use of wooden mallets instead of piercing knives for cocoa bean harvest to reduce beans' exposure to diseases and other contaminants.

Processing. All 13 projects included FLW interventions that involved: a) improved product processing to increase storage time; and b) hygienic measures to promote food safety. Many processing interventions also involved training. Some involved both new processing equipment and training to use current equipment properly. Processing interventions involving value-added products were not considered here, although some projects charted opportunities for preservation and longer-term storage to increase income. Examples of processing interventions included:

- AGP-AMDe (Ethiopia) improved the ability of the Ethiopian Commodity Exchange to evaluate and grade the quality of green coffee beans and document product traceability.
- Chanje (Haiti) supported new techniques to dry mangos and add value to other export-bound products, in partnership with the farmer association ADAIM.
- CPM (Uganda) provided farmers with equipment needed for processing, including bean threshers, cleaning tools, and tarpaulins.

- MARKETS II (Nigeria) developed interventions and techniques for fish processing at larger scales, including smoking and drying methods, based on recommendations and needs of fish producers and processors to scale-up their operations.
- RDCP (Rwanda) developed potential areas of investments for dairy processing, including value-added products that process milk.

Storage. Most projects with FLW interventions included improved product storage. Capital-intensive interventions included providing storage containers or equipment to fabricate packaging. Some storage interventions combined education and innovation by training producers on new methods to store products or create storage infrastructure. Storage interventions considered the need for cooling or refrigeration devices and facilities for highly perishable products like meat or dairy. Examples of storage interventions included:

- ADVANCE (Ghana) introduced training to demonstrate construction of improved storage silos that are made by hand using locally available, often natural, materials.
- AGP-AMDe (Ethiopia) leveraged the accessibility of portable bag-stitching machines for processors to enable increased storage efficiency that minimizes waste.
- Camel Milk (Ethiopia) provided containers for more hygienic milk storage.
- Chanje (Haiti) promoted improved storage and transportation structures, such as plastic crates, to decrease bruising and blemishes of fresh products such as mangos.
- FED (Liberia) hosted training sessions on the construction and feasibility of low-energy refrigeration facilities and charcoal-based cool storage units.
- FED (Liberia) supported training on pest control methods, including fabrication of rat guards to minimize disease, contamination, and product loss.
- KAVES (Kenya) promoted a hermetic storage bag technology to store maize for personal use at home.

Transportation. Many interventions in the transportation stage were also applicable at the storage stage, as it is economical and efficient for storage solutions to also be safe and efficient for transport. Some transportation interventions noted the importance of well-maintained and accessible roadways and systems to connect various value chain stakeholders. A few interventions focused on strategically located collection and distribution centers, in order to facilitate access by a substantial number of producers, processors, and distributors. Project examples of transportation interventions include:

- Camel Milk (Ethiopia) identified a shortcoming of temperature-controlled storage and transport systems, denoting a need for cold-chain interventions.
- Chanje (Haiti) introduced pack frames that safely store and protect products during transport on the backs of donkeys. This was especially useful in locations inaccessible to vehicles.
- Chanje (Haiti) facilitated infrastructure development, including road restoration, with financial support from development partners.
- KAVES (Kenya) supported collection centers that increased milk storage capacity.

FLW loss by agricultural supply chain

Data from interventions in dairy, maize, rice, vegetables, and other products show that the percentages of FLW and the impacts of interventions varied greatly by product (Table 2). Overall, most agricultural supply chains involved a range of FLW interventions (Table 3) with large reductions in overall FLW.

- **Dairy.** Food loss reduction estimates varied greatly among the dairy projects in the study. As shown in Table 2, FLW estimates ranged from 5-50% in the BAU approach and declined 4-10% as a result of intervention. CMVCD and RDCP both estimated major reductions in FLW due to project interventions (40 and 25 percentage point reductions, respectively). LPIN and KAVES estimated moderate reductions in FLW (10 and 1.5 percentage point reductions, respectively) due to project interventions. Although all four projects promoted practices to reduce FLW in multiple stages of the value chain (production, processing, and storage), CMVCD and RDCP estimated much higher existing levels of food loss than PIN and KAVES.
- **Maize.** Projects estimated that existing FLW rates of 5-30% for maize could be reduced to 3-17% with project interventions. ADVANCE II estimated the largest

change in FLW, a 20-percentage point reduction, partially due to improved storage from construction of new silos.

- **Vegetables.** Projects estimated that BAU of FLW for vegetables ranged from 18-38%, and may be decreased to 5-20% through project interventions. Estimates varied widely, based on crop and level of market development. HARVEST estimated a 20% reduction in FLW due to dramatic improvements in PHL handling. Chanje and ACCESO aimed to reduce FLW of vegetables through improved storage and transportation.
- **Rice.** Projects estimated that BAU for FLW of 13-30% in rice could be reduced to 3-22% due to project interventions. HARVEST estimated the greatest reduction (20%) in FLW, attributing it to interventions in storage and processing (drying). MARKETS II estimated little change (2.5%) in FLW as it focused on milling of rice as well as loss in other crops.
- **Market goods.** The remaining products cover a variety of foods, including fruits, perennials, legumes, and grains. Estimated BAU of FLW ranged from 1-30% and are reduced to 0-16% through project interventions.

Table 2. FLW estimates by product category, without and with project interventions

			FLW		
Project	**Product**	**Country**	Without project	With project	Percentage change
CMVCD	Dairy (camels)	Ethiopia	50%	10%	-40%
Rdairy	Dairy (cattle)	Rwanda	30%	5%	-25%
LPIN	Dairy (cattle)	Bangladesh	17%	7%	-10%
KAVES	Dairy (cattle)	Kenya	5%	4%	-2%
HARVEST	Maize	Cambodia	30%	10%	-20%
ADVANCE II	Maize	Ghana	30%	10%	-20%
Chanje	Maize	Haiti	30%	16%	-14%
AGP-AMDe	Maize	Ethiopia	23%	12%	-11%
ACCESO	Maize	Honduras	20%	10%	-10%
CPM	Maize	Uganda	25%	17%	-8%
KAVES	Maize	Kenya	15%	9%	-6%
MARKETS II	Maize	Nigeria	13%	10%	-3%
BLA	Maize	Zambia	5%	3%	-2%
HARVEST	Bitter gourd	Cambodia	30%	10%	-20%
HARVEST	Cucumber	Cambodia	30%	10%	-20%
HARVEST	Eggplant	Cambodia	30%	10%	-20%
HARVEST	Long bean	Cambodia	30%	10%	-20%
Chanje	Plantain	Haiti	32%	15%	-17%
ACCESO	Plantain	Honduras	20%	5%	-15%
KAVES	Potato	Kenya	18%	8%	-10%
MARKETS II	Cassava	Nigeria	38%	20%	-18%
HARVEST	Rice (irrigated)	Cambodia	20%	5%	-15%
BLA	Rice (rainfed)	Zambia	15%	3%	-12%
Chanje	Rice (irrigated)	Haiti	27%	15%	-12%
ADVANCE II	Rice (upland)	Ghana	20%	10%	-10%
ADVANCE II	Rice (flooded)	Ghana	20%	10%	-10%
ADVANCE II	Rice (irrigated)	Ghana	20%	10%	-10%
FED	Rice (rainfed)	Liberia	30%	22%	-8%
MARKETS II	Rice (irrigated)	Nigeria	18%	10%	-8%
CVC	Rice (irrigated)	Mali	10%	5%	-5%
MARKETS II	Rice (rainfed)	Nigeria	13%	10%	-3%
BLA	Soybean	Zambia	30%	10%	-20%
MARKETS II	Soybean	Nigeria	20%	5%	-15%
Chanje	Beans	Haiti	30%	15%	-15%
Chanje	Mango	Haiti	25%	16%	-9%
CPM	Beans	Uganda	18%	11%	-7%
AGP-AMDe	Coffee	Ethiopia	18%	11%	-7%
AGP-AMDe	Wheat	Ethiopia	13%	7%	-6%
AGP-AMDe	Sesame	Ethiopia	10%	5%	-5%
CPM	Coffee	Uganda	7%	4%	-3%
BLA	Groundnut	Zambia	1%	0%	-1%

Table 3. Food loss and waste intervention support type and impact by agricultural product (tonnes).

	Dairy	Maize	Vegetables	Rice	Other
Types of Support					
Input Choice	x	x	x	x	x
Harvesting			x	x	x
Processing	x	x	x	x	x
Storage	x	x	x	x	x
Transportation	x		x		x
Impact of Support					
FLW estimate BAU (t)	235,266	249,338	220,092	122,937	62,533
FLW estimate intervention (t)	155,861	110,997	112,021	38,846	29,972
Percent change	66%	45%	51%	32%	48%

Impact of FLW reductions on GHG emissions

FLW interventions in the 13 USAID projects examined in this study could provide a total GHG emission savings of 384,000 tCO_2e/year across all projects (Figure 4) based on Tier 1 estimates from EX-ACT. This is equivalent to the emissions from almost 900,000 barrels of oil consumed, according to the EPA's GHG equivalency calculator, (EPA 2017).

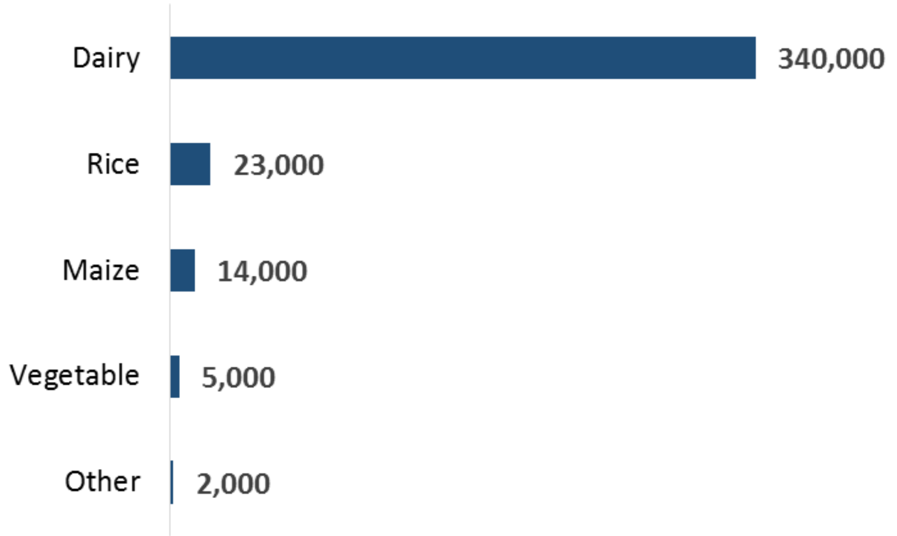


Figure 4. *Estimated emission reductions from FLW by product categories, totaling 384,000 tCO_2. Data in tCO_2e rounded to the nearest thousand.*

Estimated GHG emission reductions from FLW interventions in dairy made up almost 90 percent of total emission reductions estimated by the 13 projects studied. Amongst the four projects intervening in the dairy value chain, CMVCD and RDCP contributed the most to estimated GHG emission savings (192,542 and 119,365 tCO_2e, respectively). Both projects estimated about 80% reductions in FLW. In contrast, KAVES and LPIN had lower reductions in FLW (2-10% decreases) and therefore lower reductions in emissions (15,904 and 11,770 tCO_2e, respectively). Appendix 2 provides more information on the interventions implemented by projects.

Table 4. Range of FLW interventions examined.

Stage	Product	Country
• Input • Harvest • Processing • Storage • Transportation	• Beans • Coffee • Dairy (camels and cattle) • Groundnut • Maize • Mango • Rice • Sesame • Soybean • Wheat • Vegetables	• Ethiopia • Rwanda • Bangladesh • Kenya • Cambidia • Ghana • Haiti • Honduras • Uganda • Nigeria • Zambia • Mali

Discussion

Agricultural development projects adopted FLW activities as part of a strategy to increase food security. Ex ante emission estimates suggest reducing FLW may offer a significant and under-utilized opportunity for increasing productivity and mitigating greenhouse gas emissions, two pillars of climate-smart agriculture.

The data collected here demonstrate the potential of FLW interventions to reduce emissions in the agricultural sector, suggesting that FLW interventions should be considered by both agriculture and climate change project designers. The range of FLW interventions examined (Table 4.) – by stage product and country – is not adequately captured in existing literature or organizational reports. New insights to specific ways FLW interventions can contribute to food security and emissions reductions should be used to inform FLW strategies for future agricultural projects.

This research also shows that USAID's current market-systems approach to FLW is contributing to emission reductions. No single FLW solution emerged from the research, pointing to the need for strategies that address challenges across crops, value chain stages, and countries. This information mirrors research findings by Sheahan & Barrett 2016 suggesting that context-dependent strategies are necessary. For funding agencies to support interventions for FLW and emissions reductions, the type of information presented here is needed to fill a gap between literature based on global analyses and activities implemented at the project level.

While some interventions achieved seemingly small reductions in FLW per area or per animal unit, their net mitigation benefits were significant when implemented at large scales. For example, direct emission reductions from FLW interventions in dairy accounted for almost 90% of the total FLW emission savings found in this study. These improvements were possible because a) dairy cattle produce large amounts of GHG emissions and b) dairy production systems have high rates of FLW. KAVES reduced FLW in dairy from a rate of 5% to a rate of 3.5%. This 30% reduction involved 435,000 animals and significantly increased available product. It should be noted that Sub-Saharan African countries average 10% postharvest FLW (FAO 2011); comparatively the KAVES project began with a relatively small FLW. Conversely, in croplands, HARVEST reported this average high rate of FLW reduction (67% per tonne of vegetables), but its small implementation area (131 to 2,095 ha) resulted in a relatively small reduction in actual FLW and emissions.

In addition to the data on FLW interventions and associated low emissions development and emission reduction opportunities, the methods used in this study should inform future FLW monitoring, reporting and verification (MRV). FLW estimates could be improved by collecting baseline food loss data. Projects lacked a common framework for reporting FLW interventions, making it difficult to execute cross-project comparisons, learning, and validation of estimates. There is also a need to verify FLW and FLW-reduction estimates via independent methods. Scientifically rigorous and comparable MRV systems would allow for systematic analysis of the technical efficacy, cost-effectiveness, and potential adoption hurdles of FLW interventions across local contexts and production systems.

Conclusion

Our literature review revealed only 23 studies addressing GHG emissions resulting from FLW. Few FLW research studies have investigated interventions across a range of value chains in multiple countries, likely due to the difficulties in collecting and synthesizing multi-country estimates. Published studies have also not adequately estimated the emission savings potential of FLW initiatives in developing countries. The majority of existing literature frames GHG emissions in the context of global estimates of FLW or makes regional- or country-level estimates for specific value chain phases. Prior to this study, only one article presented primary information on FLW, and it addressed only two crops within a region of Brazil (Goldsmith et al. 2015). Documenting and analyzing interventions and opportunities that reduce emissions while increasing food security, as done here, builds an evidence base for future policy and management decisions.

By investigating food losses within Feed the Future, our research team had the unique opportunity to study FLW interventions across extended value chains in multiple countries. This study aims to address part of this info gap by examining how reducing FLW impacts emissions in the context of agricultural development progress. We recommend further analyses of the technical efficacy, cost-effectiveness, and potential adoption hurdles of alternative FLW interventions in specific local contexts.

Because reducing FLW leaves more food available for consumption and sale, while also reducing GHG emissions, it decouples trajectories of economic growth and GHG emissions. The Feed the Future projects examined by this study also illustrate how climate-smart agricultural development can increase food security – the primary objective for which these projects were designed – by increasing effective food or product availability after FLW and decreasing emission intensity. Our analysis also shows that market-based approaches can achieve both FLW and emission reductions. This study, as most FLW studies, does not account for the possibility of increased emissions introduced by new processing methods, storage, or transportation interventions that could be estimated with full life cycle analyses. Using a broader framework for FLW analyses could expand the range of project interventions, for example to efficiently cool and transport, while accounting for potential additions in emissions from increased fuel use. We expect that emission intensity from interventions will remain lower than the business-as-usual development trajectory, even in a life-cycle analysis perspective.

Cost-effective reductions in FLW benefit actors throughout the value chain, beginning with the producers. Small changes in FLW can have large impacts on food security among smallholder farmers and dairy producers. At the regional and national scales, reduced FLW increases food security while decreasing emission intensity of products. Agriculture and climate change actors and project developers should consider FLW interventions.

References

Affognon H, Mutungi C, Sanginga P, Borgemeister C. 2015. Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis. *World Development*, 66:49–68.

Aulakh J, Regmi A, Fulton J, Alexander C. 2013. Food Losses: Developing a Consistent Global Estimation Framework. Agricultural and applied economics association annual meeting, August 4–6, Washington, D.C. USA

Bahadur KC K, Haque I, Legwegoh AF, Fraser ED. 2016. Strategies to Reduce Food Loss in the Global South. *Sustainability*, 8(595):1–13.

Baoua IB, Amadou L, Ousmane B, Baributsa D, Murdock LL. 2014. PICS bags for post-harvest storage of maize grain in West Africa. *Journal of Stored Products Research*, 58:20–28.

Beddington J, Asaduzzaman M, Clark M, Fernández A, Guillou M, Jahn M, Erda L, Mamo T, Van Bo N, Nobre C, Scholes R, Sharma R, Wakhungu J. 2012. Achieving Food Security in the Face of Climate Change: Final Report from the Commission on Sustainable Agriculture and Climate Change. (Available online at: http://ccafs.cgiar.org/sites/default/files/assets/docs/climate_food_commission-final-mar2012.pdf) (Accessed 22 September 2016)

Bernoux M, Branca G, Carro A, Lipper L, Smith G, Bockel L. 2010. Ex-ante greenhouse gas balance of agriculture and forestry development programs. *Scientia Agricola*, 67(1):31–40.

Bockel L, Grewer U, Fernandez C, Bernoux M. 2013. EX-ACT users manual: estimating and targeting green house gas mitigation in agriculture. Rome: FAO. (Available from: http://www.fao.org/tc/exact/user- guidelines)

Bonicet AJ. 2013. Evaluation of Postharvest Losses and Potential New Methods for the Harvest, Transport and Temperature Management of Haitian Mangos Destined for Export Markets. MS thesis. Gainesville, Florida: University of Florida. Department of Horticultural Sciences.

De Groote H, Kimenju SC, Likhayo P, Kanampiu F, Tefera T, Hellin J. 2013. Effectiveness of hermetic systems in controlling maize storage pests in Kenya. *Journal of Stored Products Research*, 53:27–36.

[FAO] Food and Agriculture Organization of the United Nations. 2011. Global food losses and food waste. Rome: Food and Agriculture Organization of the United Nations, FAO.

Garnett T. 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy*, 36, Supplement 1, S23–S32.

Global Knowledge Initiative. 2014. Reducing Global Food Waste and Spoilage: Assessing resources needed and available to reduce post harvest food loss in Africa. A Rockefeller Foundation report.

Goldsmith PD, Martins AG, de Moura AD. 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.

Grewer U, Bockel L, Galford G, Gurwick N, Nash J, Pirolli G, Wollenberg E. 2016. A methodology for greenhouse gas emissions and carbon sequestration assessments in agriculture: Supplemental materials for USAID case studies of low emissions development in agriculture. CCAFS Working Paper no. 187. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R, Meybeck A. 2011. Global food losses and food waste. Rome: Food and Agriculture Organization of the United Nations, FAO.

Hell K, Mutegi C, Fandohan P. 2010. Aflatoxin control and prevention strategies in maize for Sub-Saharan Africa. *Julius-Kühn-Archiv*, 0(425):534.

Hiç C, Pradhan P, Rybski D, Kropp JP. 2016. Food Surplus and Its Climate Burdens. *Environmental Science & Technology*, 50(8):4269–4277.

[HLPE] High Level Panel of Experts on Food Security and Nutrition. 2014. Food losses and waste in the context of sustainable food systems. Rome.

Hodges RJ, Buzby JC, Bennett B. 2011. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *The Journal of Agricultural Science*, 149:37–45.

Karlovsky P, Suman M, Berthiller F, Meester JD, Eisenbrand G, Perrin I, Oswald IP, Speijers G, Chiodini A, Recker T, Dussort P. 2016. Impact of food processing and detoxification treatments on mycotoxin contamination. *Mycotoxin Research*, 32(4):179–205.

Kendall HW, Pimental D. 1994. Constraints on the expansion of the global food supply. *Ambio,* 198-205.

Kummu M, de Moel H, Porkka M, Siebert S, Varis O, Ward PJ. 2012. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of The Total Environment*, 438:477–489.

Lipinski B, Hanson C, Lomax J, Kitinoja L, Waite R, Searchinger T. 2013. Reducing food loss and waste. World Resources Institute Working Paper.

Liu J, Lundqvist J, Weinberg J, Gustafsson J. 2013. Food Losses and Waste in China and Their Implication for Water and Land. *Environmental Science & Technology*, 47(18):10137–10144.

Lore T, Omore AO, Staal SJ. 2005. Types, levels and causes of post-harvest milk and dairy losses in sub-Saharan Africa and the Near East: Phase two synthesis report. Nairobi: ILRI. (Available online at: https://cgspace.cgiar.org/handle/10568/3741) (Accessed 24 January 2017)

MacCartee J. 2013. Preventing Postharvest Losses from Field to Market: A Food Security Imperative. (Available online at: https://agrilinks.org/events/preventing-postharvest-losses-field-market-food-security-imperative) (Accessed 29 January 2017)

Munesue Y, Masui T, Fushima T. 2014. The effects of reducing food losses and food waste on global food insecurity, natural resources, and greenhouse gas emissions. *Environmental Economics and Policy Studies*, 17(1):43–77.

Opara UL, Mditshwa A. 2013. A review on the role of packaging in securing food system: Adding value to food products and reducing losses and waste. *African Journal of Agricultural Research*, 8(22):2621–2630.

Parfitt J, Barthel M, Macnaughton S. 2010. Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 365:3065–3081.

Paulsen MR, Kalita PK, Rausch KD. 2015. Postharvest Losses due to Harvesting Operations in Developing Countries: A Review. ASABE Paper No. 152176663. St. Joseph, Mich.: ASABE.

Pessu PO, Agoda S, Isong IU, Ikotun I, Atanda SA. 2011. The concepts and problems of postharvest food losses in perishable crops. *African Journal of Food Science*, 5(11):603–613.

Porter SD, Reay DS. 2015. Addressing food supply chain and consumption inefficiencies: potential for climate change mitigation. *Regional Environmental Change*, 1–12.

Prusky D. 2011. Reduction of the incidence of postharvest quality losses, and future prospects. *Food Security*, 3(4):463–474.

Rani PR, Chelladurai V, Jayas DS, White NDG, Kavitha-Abirami CV. 2013. Storage studies on pinto beans under different moisture contents and temperature regimes. *Journal of Stored Products Research*, 52:8–85.

Reay DS, Davidson EA, Smith KA, Smith P, Melillo JM, Dentener F, Crutzen PJ. 2012. Global agriculture and nitrous oxide emissions. *Nature Climate Change*, 2(6):410–416.

Rosegrant MW, Magalhaes E, Valmonte-Santos RA, D'Croz DM. 2015. Returns to investments in reducing postharvest food losses and Increasing Agricultural Productivity growth. Working paper. CGIAR.

Rosenstock TS, Lamanna C, Chesterman S, Bell P, Arslan A, Richards M, Rioux J, Akinleye AO, Champalle C, Cheng Z, Corner-Dolloff C, Dohn J, English W, Eyrich AS, Girvetz EH, Kerr A, Lizarazo M, Madalinska A, McFatridge S, Morris KS, Namoi N, Poultouchidou N, Ravina da Silva M, Rayess S, Ström H, Tully KL, Zhou W. 2016. The scientific basis of climate-smart agriculture: A systematic review protocol. CCAFS Working Paper no. 138. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Sheahan M, Barrett CB. 2016. Food loss and waste in Sub-Saharan Africa: A critical review. (Available online at: http://barrett.dyson.cornell.edu/files/papers/Sheahan%20Barrett_post-harvest%20losses_FULL%20TEXT.pdf) (Accessed 21 September 2016)

Sims R, Flammini A, Puri M, Bracco S. 2015. Opportunities for Agri-Food Chains to become Energy-Smart. (Available online at: http://www.fao.org/publications/card/en/c/0ca1c73e-18ab-4dba-81b0-f8e480c37113) (Accessed 4 October 2016)

Smith P, Haberl H, Popp A, Erb K, Lauk C, Harper R, Tubiello F, de Siqueira Pinto A, Jafari M, Sohi S, Masera O, Böttcher H, Berndes G, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, Mbow C, Ravindranath N, Rice C, Robledo Abad C, Romanovskaya A, Sperling F, Herrero M, House J, Rose, S. 2013. How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology*, 19(8):2285–2302.

Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, Haberl H, Harper R, House J, Jafari M, Masera O, Mbow C, Ravindranath NH, Rice CW, Robledo Abad C, Romanovskaya A, Sperling F, Tubiello F. 2014. Agriculture, Forestry and Other Land Use (AFOLU). In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T, Minx JC (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Stathers T, Lamboll R, Mvumi BM. 2013. Postharvest agriculture in changing climates: its importance to African smallholder farmers. *Food Security*, 5(3):361–392.

Stear MJ, Bishop SC, Mallard BA, Raadsma H. 2001. The sustainability, feasibility and desirability of breeding livestock for disease resistance. *Research in Veterinary Science*, 71(1):1–7.

Tubiello FN, Salvatore M, Ferrara AF, House J, Federici S, Rossi S, Biancalani R, Condor Golec RD, Jacobs H, Flammani A, Prosperi P, Cardenas-Galindo P, Schmidhuber J, Sanz Sanchez MJ, Srivastava N, Smith P. 2015. The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990–2012. *Global Change Biology*, 21(7):2655–2660.

Vermeulen SJ, Campbell BM, Ingram JSI. 2012. Climate Change and Food Systems. *Annual Review of Environment and Resources*, 37(1):195–222.

Appendix 1: Summary table of FLW and GHG literature

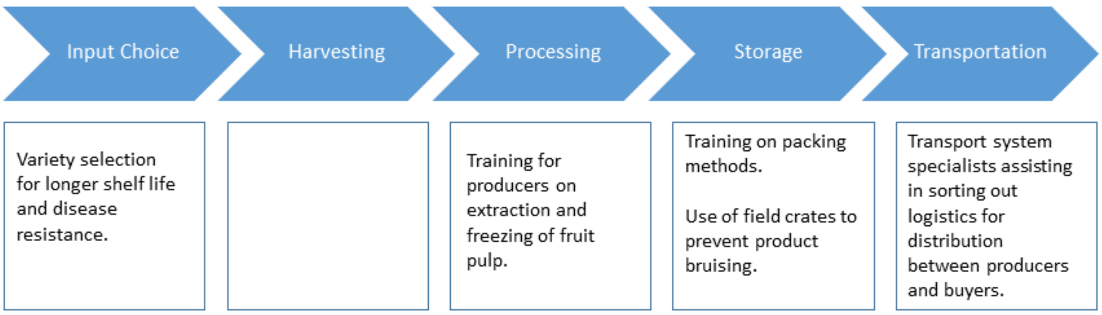
Author	Geographic extent	Developed/ developing country?	Collected data on FLW	Collected data on GHG estimates	Calculated FLW estimate	Calculated GHG estimate
Affognon, Mutungi, Sanginga, & Borgemeister, 2015	Sub-Saharan Africa	Developing	No	No	N/A	N/A
Aulakh, Regmi, Fulton, & Alexander, 2013	Global	Both	N/a	No	No	N/a
Beddington et al., 2012	Global	Both	No	No	No	No
Garnett, 2011	Multi-scale	Both	No	No	N/A	N/A
Global Knowledge Intiative, 2014	Africa	Developing	No	No	No	N/A
Goldsmith, Martins, & de Moura, 2015	Mato Grasso, Brazil	Developing	Yes	No	Yes	N/A
Gustavsson, Cederberg, Sonesson, Van Otterdijk, & Meybeck, 2011	Global, regional	Both	No	No	Yes	No
Hiç, Pradhan, Rybski, & Kropp, 2016	Global	Both	No	No	Yes	Yes
HLPE, 2014	Global	Developing	No	No	No	No
Kummu et al., 2012	Global	Both	No	No	Yes	N/A
Lipinski et al., 2013	Global	Both	No	No	Yes	No
Liu, Lundqvist, Weinberg, & Gustafsson, 2013	China	Developing	No	No	No	N/A
Munesue, Masui, & Fushima, 2014	Global	Both	No	No	No	No
Parfitt, Barthel, & Macnaughton, 2010	Global	Both	No	No	No	No
Porter & Reay, 2015	Global	Both	No	No	No	Yes
Reay et al., 2012	Global	Both	No	No	N/A	Yes
Rosenstock et al., 2016	Global	Developing	No	No	N/A	N/A
Sheahan & Barrett, 2016	Sub-Saharan Africa	Developing	No	No	No	N/A
Sims, Flammini, Puri, & Bracco, 2015	Global	Both	No	No	No	Yes
Smith et al., 2013	Global	Both	No	No	No	Yes
Stathers, Lamboll, & Mvumi, 2013	Sub-Saharan Africa	Developing	No	No	N/A	N/A
Tubiello et al., 2015	Global	Both	No	No	N/A	No
Vermeulen, Campbell, & Ingram, 2012	Global	Both	No	No	No	No

Appendix 2: Description of food loss and waste interventions by project

ACCESO

Project overview. ACCESO was a four-year Feed the Future activity that began in 2011 and was implemented by Fintrac Inc. It aimed to increase nutrition and incomes of 30,000 smallholder farmer households by introducing improved agricultural production practices; creating market-driven programs to increase production and sales of high-value cash crops; and expanding off-farm microenterprise and employment opportunities. ACCESO provided technical assistance and training at the household and community levels to increase capacity in agricultural production, marketing, postharvest, and value-added processing; link up with market opportunities; prevent malnutrition; and improve management of natural resources and the environment. ACCESO operated in six departments of western Honduras: Intibucá, La Paz, Ocotepeque, Lempira, Copán, and Santa Bárbara.

Types of FLW interventions in ACCESO project

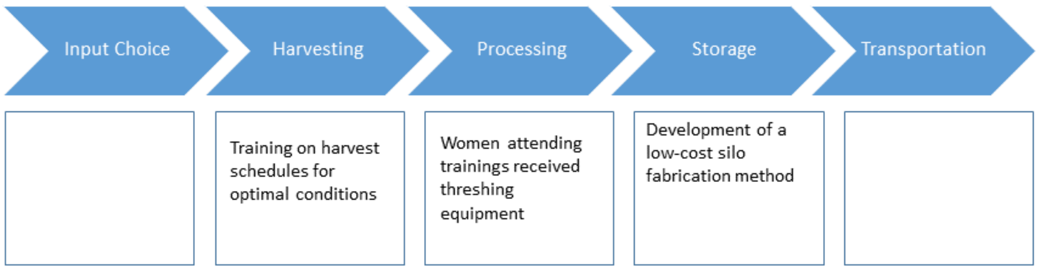


FLW interventions. ACCESO promoted practices to reduce food loss across the various stages in the targeted food value chain. The project promoted shelf-life analyses for 12 yellow onion varieties in order to identify the longest shelf life and lowest susceptibility to disease. It supported training producers on processing techniques to efficiently extract and freeze fruit pulp, contributing to increased retail prices per kilo as compared to raw fruit that would eventually be used for juice and other processed products. ACCESO also supported training on techniques and methods to properly and efficiently pack vegetables that would be sent to more formal markets. ACCESO introduced field crates to store produce during transportation to prevent bruising during shipment. Finally, trained specialists were able to assist in making transportation logistics more efficient and sharing details for transit between producers and buyers.

ADVANCE II

Project overview. ADVANCE II was a 4.5-year project funded by the Feed the Future initiative and implemented by ACDI/VOCA. Begun in 2014, the goal of ADVANCE II was to scale up private sector investment in the maize, rice, and soybean value chains to achieve greater food security among the rural population in northern Ghana. ADVANCE II promote the adoption of improved practices in three activity components: to increase the productivity of targeted value chains; to increase access to markets and trade for smallholder farmers; and to strengthen and build local capacity. ADVANCE II supported farmer training in demonstration plots; indirect knowledge transmission from out-grower businesses to smallholder farmers; and provision of mechanized land preparation and postharvest grain management by commercial service providers.

Types of FLW interventions in ADVANCE project

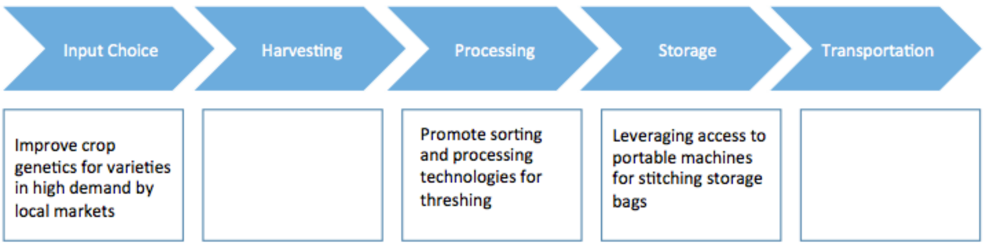


FLW interventions. ADVANCE II identified and promoted techniques for reducing FLW in rice cultivation through training producers on optimal moisture levels for harvest. In one initiative, women who attended special demonstrations received training and equipment for processing to be used on threshing floors. To reduce losses during storage, a project participant directed construction of handmade silos. Using accessible and low-cost components for fabrication, producers built storage facilities using mud and dried straw that were reinforced and virtually free from cracks.

Agricultural Growth Project

Project overview. Based in Ethiopia, Agricultural Growth Project (AGP) was a five-year collaboration between the country's national government, the World Bank, and various funding stakeholders, including USAID. Focused on promoting economic development in agricultural regions with potential for growth, the project strove to decrease the poverty rate and instances of hunger through sustainable value chain interventions. Using a whole-systems value chain process, the project integrated the collaboration of value chain actors to develop synergistic interventions. Of four distinctive components in the project, the main focus analysed was to enhance the competitiveness of maize, wheat, sesame, and coffee value chains.

Types of FLW Interventions in AGP Project

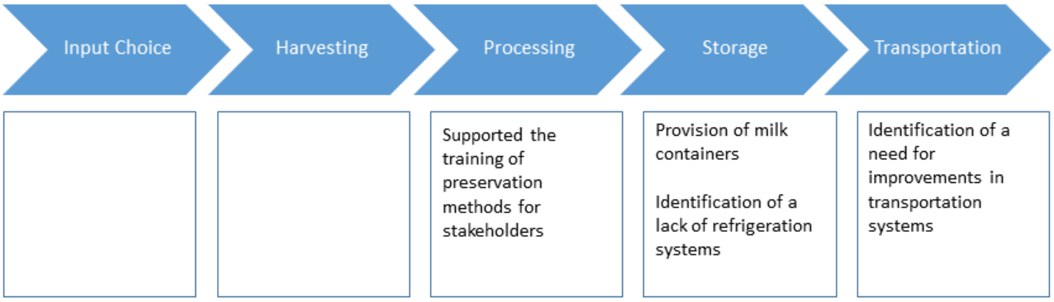


FLW Interventions. AGP emphasized interventions at various stages, beginning with pre-harvest. The project promoted and increased the productivity and capacity for cooperatives by genetically improving chickpea varieties that were in high demand by the local market. The implemented work also improved the Ethiopian Commodity Exchange's capacity to assess and trace the quality and grading of green coffee beans, which led to more profitability and higher revenue on the market. By partnering with over fifty wheat smallholder cooperatives, AGP promoted sorting and processing technology for wheat threshing which decreased the amount and frequency of wheat loss. Finally, the project leveraged the access to machines that can portably stitch bags for storage of the products

Camel Milk

Project overview. The Aged and Children Pastoralists Association implemented the USAID Feed the Future-funded Camel Milk project from December 2012 through December 2016. Camel Milk aimed to increase incomes and enhance nutritional status of targeted households in the Siti (Shinile) and Fafan (Jijiga) zones of the Somali region of Ethiopia. The project had three components: to increase camel productivity, to improve milk hygiene and quality, and to strengthen market access and trade linkages. The activity introduced improved management practices to a herd of 247,000 camels managed by herders from approximately 16,500 households. Key actors included the Somali Region Bureau of Livestock, Crop and Rural Development; the Somali Pastoral and Agro-pastoral Research Institute; and processors, traders, community animal health workers, animal feed producers, suppliers, aggregators, and transporters.

Types of FLW interventions in Camel Milk project

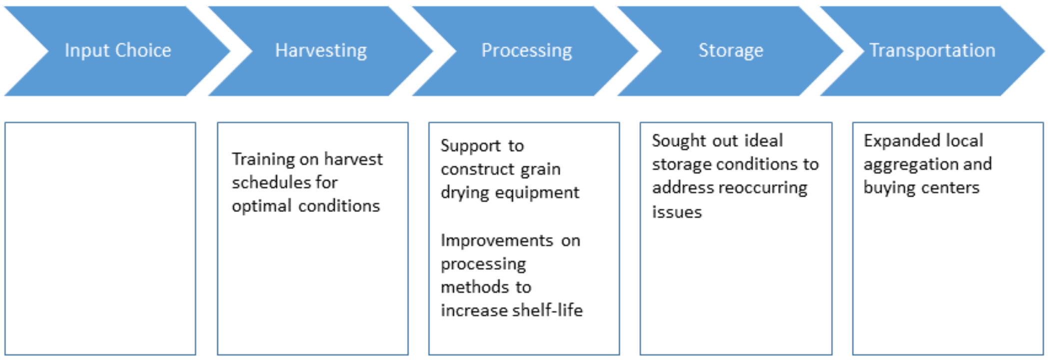


FLW interventions. Camel Milk promoted practices to reduce FLW across the chain. The project supported teaching milk preservation techniques to individual producers and cooperatives. Trainings and related materials also promoted ways to decrease milk spoilage; for example, the project provided milk containers to improve storage. The project identified the inadequacy of refrigeration and transportation systems, suggesting the need for interventions in long-term storage and distribution of milk in the region.

Commodity Production and Marketing

Project overview. CPM was a five-year USAID Feed the Future project implemented by Chemonics International, Inc. begun in 2013. It aimed to achieve a sustainable increase in the production and marketing of high-quality maize, beans, and coffee in 56 Feed the Future focus districts in Uganda. CPM sought to increase crop productivity; increase the availability and effectiveness of support services; strengthen value chain relationships for more effective movement of produce and information between buyers and sellers; and increase access to domestic, regional, and international markets. CPM aimed to reach 400,000 beneficiaries.

Types of FLW interventions in CPM project

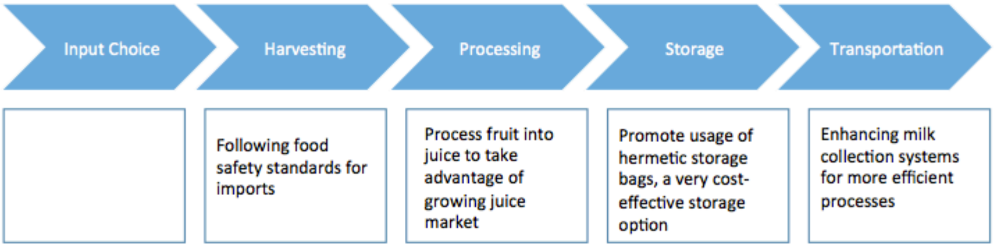


FLW interventions. CPM promoted practices to reduce FLW across at four stages in the value chain for the products mentioned above. Training supported by this project taught producers and traders about optimal harvesting schedules and conditions. Processing interventions strove to address issues of quality reduction related to poor drying, processing, and storage conditions. Interventions supported construction and evaluation of grain-drying equipment with the goal of decreasing aflatoxin levels. After identifying the causes of degradation during storage, the project emphasized interventions during processing to enhance storage shelf-life. In addition, CPM helped to establish and expand partnerships for additional aggregation and buying centers, as well as mobile shellers for coffee. CPM analyzed and addressed differing gender roles to ensure that women also received equipment they needed, including tarpaulins, threshers for beans, and cleaning tools.

Kenya Agricultural Value Chain Enterprise

Project overview. Kenya Agricultural Value Chain Enterprise (KAVES) was funded for a 5-year project by USAID. The goal of the project was to increase the output productivity and income of 500,000 agricultural smallholders in 21 counties in Kenya. Stakeholder partners included the farmers, local businesses, and county and national government offices, in addition to value chain stakeholders such as processors, input suppliers, transportation specialists, retailers, and financiers. By bridging these connections, KAVES helped to improve the price and value of products and services within an expanded market, both local and international through exports.

Types of FLW Interventions in KAVES Project

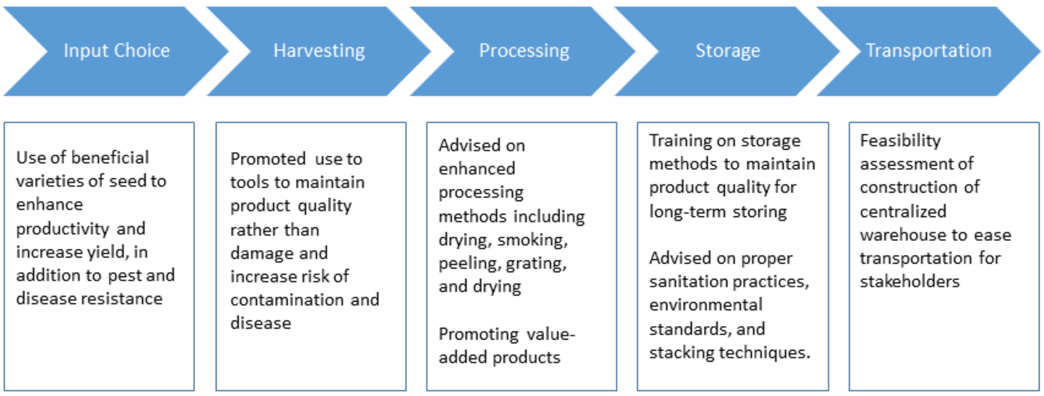


FLW Interventions. KAVES focused on agricultural and PHL activity for maize, potato, and dairy. One notable intervention was meeting imported food safety standards, for example by evaluating moisture content and aflatoxin presence. By emphasizing market connections, KAVES partnered with fruit processors to connect smallholder farmers to opportunities to increase their fruit production, recognizing an increase in demand for tropical fruit juices. The project also prioritized storage technologies that could be more accessible for farmers. Namely, hermetic storage bags developed by Purdue University are more efficient for grain storage. KAVES promotes the use of the bags for home grain storage as a cost-effective method. For transportation, milk collective systems were improved to be more efficient. To increase the capacity for milk bulk, 25 storage and collection centres were enhanced. These centres aim to be more accessible for farmers location-wise, in addition to connecting them with services and goods such as animal health, reproduction, and feed services.

MARKETS II

Project overview. MARKETS II was a five-year project that began in 2012, funded by USAID Feed the Future and implemented by Chemonics International, Inc. The activity aimed to improve food security and reduce poverty by promoting agricultural development in aquaculture, cassava, cocoa, rice, and sorghum production systems and maize and soybeans value chains. MARKETS II sought to increase access to adequately-priced agricultural inputs and retail/wholesale markets. It also strove to increase access to finance as well as to identify new markets. This resulted in increased production and quality of produce.

Types of FLW interventions in MARKETS II project

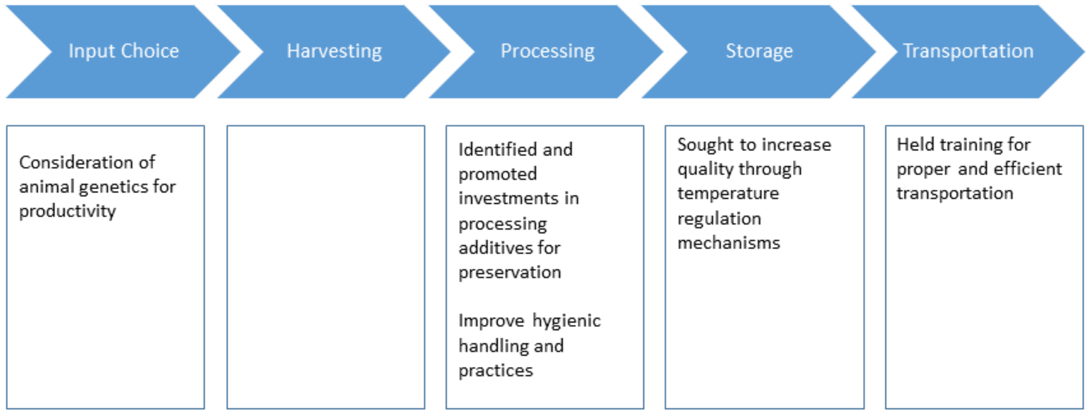


FLW interventions. MARKETS II promoted a wide range of FLW interventions. For cocoa, the project promoted a) varieties that were more resistant to pests and disease and b) improved harvesting techniques, such as use of wooden mallets that reduce damage to beans, and thus exposure to disease or contamination. MARKETS II supported aquaculture farmers to enhance methods of preservation, including drying and smoking. For cassava growers, the project advanced a partnership to design and promote processing equipment, including peelers, graters, and drying devices, and promoted their availability in order to create value-added products. Training on preservation methods of cassava focused on maintaining product quality during long periods of storage. The project also supported a feasibility assessment with a local rice mill to create payment plans for producers and to purchase measurement tools to gauge environmental conditions. In rice, the project documented how construction of a strategically placed warehouse for local paddy producers would ease transportation problems.

Rwanda Dairy

Project overview. RDCP II was a five-year project funded by USAID's Feed the Future initiative implemented by Land O'Lakes. Begun in 2012, RDCP II aimed to enhance the competitiveness of Rwandan dairy products in regional markets in order to increase rural household incomes associated with dairy-related enterprises in 17 districts across all five provinces of Rwanda. The project aimed to upgrade the dairy value chain by stimulating investment and improved management practices. RDCP II worked with smallholder producers, milk cooling centers, transporters, and processors, targeting improved livestock production systems for an estimated 50,000–63,000 dairy-producing smallholder farmers involving 150,000–200,000 cows.

Types of FLW interventions in Rwanda Dairy project



FLW interventions. RDCP II promoted several practices that reduce FLW. Interventions began early in the value chain with the selection of ideal genetics and breeding choices to improve productivity of the animals. The project identified and promoted investments in dairy processing, such as chemical additives and live cultures, that improve product shelf life. RDCP II emphasized increasing the quality of milk at all stages of the value chain, especially through temperature regulation mechanisms and hygienic practices. Stakeholders along the milk value chain received training for proper and efficient handling, hygienic production, and transportation.

RESEARCH PROGRAM ON

Climate Change, Agriculture and Food Security

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic initiative of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT). CCAFS is the world's most comprehensive global research program to examine and address the critical interactions between climate change, agriculture and food security.

For more information, visit www.ccafs.cgiar.org

Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

CCAFS is led by: CIAT

Strategic partner: futurearth

Research supported by: