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POST-HARVEST LOSSES:

Global Scale, Solutions, and Relevance to Ghana

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1. POST-HARVEST LOSS: SCALE OF THE PROBLEM

FAO defines PHL as measurable losses in edible food mass (quantity) or nutritional value (quality) of food intended for human consumption. The post-harvest system comprises a range of interconnected activities, from the time of harvest through processing, marketing, preparation, and finally consumption decisions at the consumer level. Each year, large quantities of food are wasted or lost at each of these stages during their journey to consumers.

According to an FAO-commissioned study, around one third (1.3 billion tonnes) of food produced for **human consumption is lost or wasted globally each** year [1]. Figure 1 shows that the magnitude of food losses and waste are lower in low-income regions. However, losses in sub-Saharan Africa (SSA) are higher than those in South and Southeast Asia, where incomes are higher on average, suggesting significant room for improvement in the region.

Figure 1 Food lost or wasted by region in Kcal/capita/day adapted from [27]

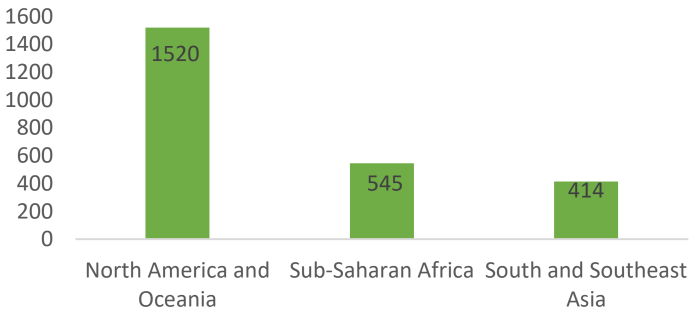
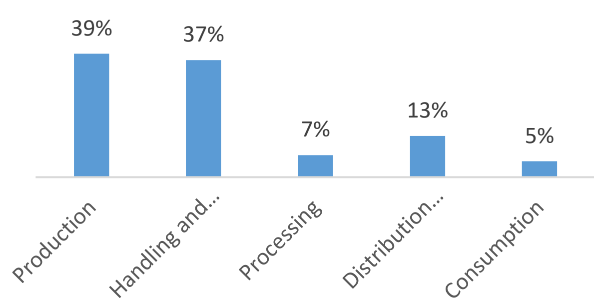


Figure 2 Food lost or wasted by stage in the value chain in sub-Saharan Africa. (Percent of Kcal lost and wasted) Adapted from [27]



Further, Figure 2 shows that the vast majority of losses in SSA occur at the production, handling and storage stages of the value chain. Such losses disproportionately affect the income of farmers, and thus pose a major challenge for poverty reduction and food security, as poverty is most acute in rural areas. In addition to increasing the incomes of producers and other value chain actors, will

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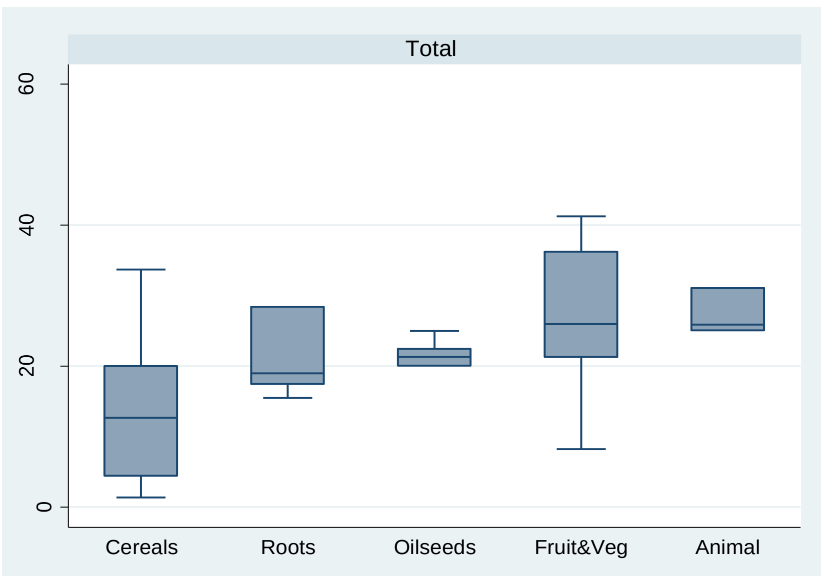
alleviate the need to bring additional land under cultivation, thereby mitigating negative environmental impacts from agriculture [2].

Figure 3 summarizes the findings of over 800 studies on post-harvest loss from around the world [3], while Table 1 summarizes the extent of physical losses among key crops in Ghana. Both the extent and nature of PHL vary greatly by crop; while most of the losses in mangoes occur at the transport and marketing stages, okra suffers most loss at the harvesting stage. Both Table 1 and Figure 3 indicate that the problem of post-harvest loss is especially acute for horticultural crops, for which losses are typically shown to range between 20 to 35%. While the proportion of maize estimated lost by one study was 14%, those for tomatoes and maize were 38% and 46% respectively [4].

Figure 3. Postharvest losses by commodity; solid boxes indicate 25th to 75th percentile of estimates, internal line shows median, lines outside boxes show 5th and 95th percentiles. Adapted from [3].



Research to quantify the extent and drivers of loss of specific crops in specific contexts is needed to identify the most cost-effective solutions to addressing post-harvest loss; this can accompany practical efforts to mitigate the problem. The remainder of this report focuses on PHL in horticulture due to the larger loss burden in this sub-sector and the nutritional and economic importance of these crops growth. To provide context, we begin with a description of horticultural production in Ghana.

Table 1. Physical losses and loss hotspots for selected commodities in Ghana, adapted from [4]

Commodity	Total losses (%)	Key loss hotspots
Maize	14	Harvesting operations (3.9%); on-farm storage (2%); transportation operations (3.4%)
Rice	13.5	Preliminary processing (5.9%); on-farm storage (4.3%)
Cowpea	10	
Yam	31.4	On-farm storage (9.8%); transportation (10.2%)
Cassava	33.6	Harvesting (4.6%); on-farm assembling (4%); transportation (7.4%); processing (8.5%); storage of dried product (5%)
Groundnuts	6.6	Packaging & bagging (1.5%); transportation (2%)
Fish	21.5	Capture (2.1%); transportation (15.5%); sorting (2.5%)
Tomato	37.5	Harvesting (4%); sorting (13.8%); transportation (14.4%)
Okra	24.2	Harvesting (16.6%); retailing (5.1%)
Mango	45.6	Sorting (5.4%); transport (13.4%); marketing (16.2%)
Orange	5	Sorting (2.2%)

2. HORTICULTURE IN GHANA

Ghana's climatic conditions are ideal for horticulture production. Policy makers and development partners view horticulture, particularly oriented toward exports, as an important opportunity for diversification of the national production base and improvement of rural livelihoods. After the Structural Adjustment Program and liberalization strategies of the 1980s, the horticulture sector grew rapidly, with dramatic growths during late 2000's as Ghana heavily invested in fruit exports [5].

Ghanaian farmers are able to exploit two seasons for horticultural production: the main April to July period, complemented by a minor season from December to February. As urban consumers in West Africa become wealthier and more health conscious, Accra and other growing cities represent important markets. A study by Tschirley et al. revealed that poor and middle-income households in East and Southern Africa spend 20 percent and 46 percent of their food budgets on perishables, respectively [6]. This suggests that as the middle class grows and poverty declines in the region, local consumption of these products will rise further.

Given its proximity and existing linkages to the markets in the EU, Ghana has great potential to leverage export-based horticulture for economic growth. A study in Kenya, a country whose agricultural production is similarly dominated by small-scale growers, found that net farm incomes of small-holder farmers who produced for export were five times higher per family member compared to those of similar farmers who did not grow horticultural products [7]. This suggests that export-based horticulture represents an important income opportunity, particularly for those with limited resources. Horticulture thus stands out as a sector with the untapped potential, within which post-harvest loss demands attention.

3. POST-HARVEST LOSSES IN GHANAIAN HORTICULTURE: MANGOES AND TOMATOES

Two important horticultural crops in Ghana, for which evidence exists on the scale of PHL and potential solutions, are mangoes and tomatoes.

Mangoes

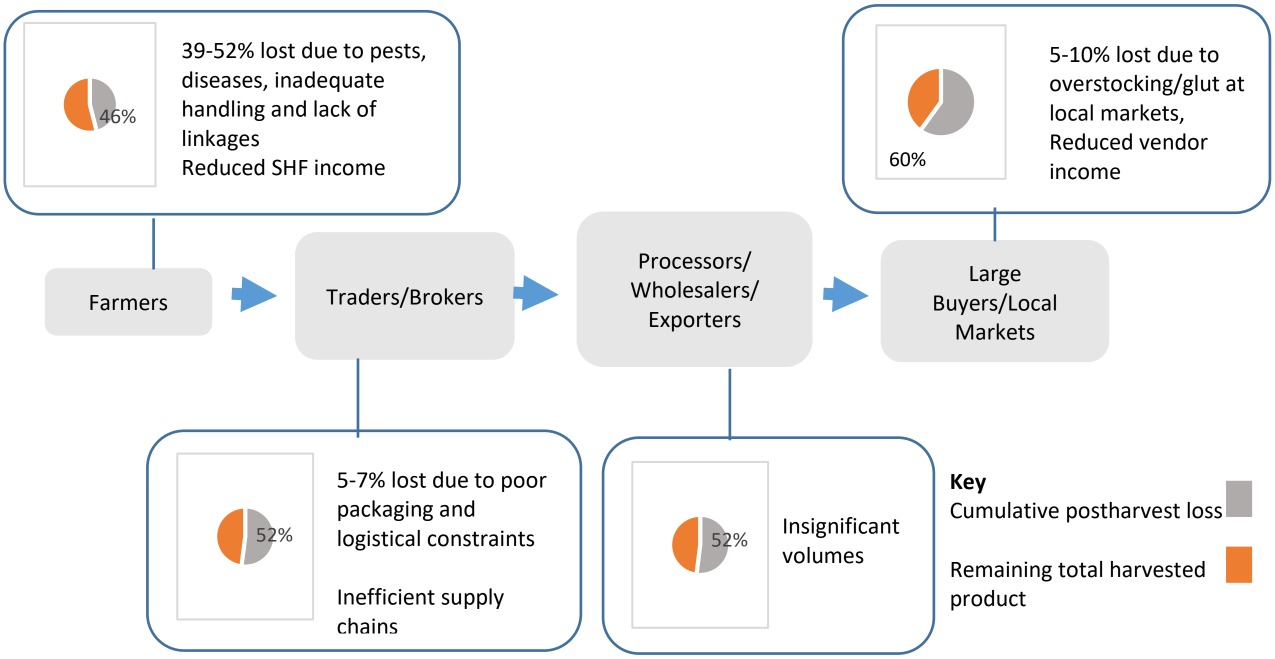
An important source of phosphorous, potassium, and multiple vitamins, mangoes are considered among the most important horticultural crops in tropical and sub-tropical regions [8]. Mango production sees excellent returns for farmers and other actors along the value chain, with profit margins of between 50 and 90 percent [9]. Ghana's agroecological characteristics make it particularly well-suited to the production of mango. In 2015, Ghana exported 2219 tonnes of mangoes, two times the amount compared to 2012 and over four times the production average of the period 2006-2010 [10]. Overall, Ghanaian mango exports are relatively minor in terms of volumes when compared to other West African suppliers. However, Ghana is a major supplier of pre-packaged ready-to-eat mango slices – an important source of value addition for the rapidly increasing EU market [11]. Demand is high both for fresh mangoes and processed products such as dried fruit, purees, and juices. In 2010, Ghana imported more than 3,000 tonnes of fresh mangoes, a third of which came all the way from Brazil. The high level of import is partially attributed to the need of juice processors such as Blue Skies to have a constant supply of fresh products in order to meet their year-round demand.

In Ghana, it has been estimated that the average loss following harvest is between 20 and 50 per cent [11]. The main reason for losses with regards to Ghanaian mango has been attributed to the fruit fly presence and a host of diseases as well as the lack of cold chain facilities, and long transit time. Related challenges include poor fruit handling practices, limited access to on-farm power, and inadequate transportation. Finally, value chain actors have limited knowledge of production potential, available varieties, and post-harvest practices.

Figure 4 summarizes the post-harvest loss along the mango value chain in Kenya, a context very similar to that of Ghana in terms of agro-climatic conditions, farming practices, and infrastructure. The main causes behind the losses are poor production and harvesting techniques, limited access to inputs such as pesticides, and poor linkages to traders and brokers. Incorrect harvesting, such as shaking of trees or waiting for the fruit to fall to the ground, can result in either immature and/or damaged fruit, while the lack of pesticide use limits protection from physical and physiological damage induced by pests. Both result in produce being rejected by traders and processors. Furthermore, poor linkages to traders and brokers leads to an excess supply of mangoes that cannot be consumed or sold. Together, these losses accounted for 39-52 percent of total mango losses and a significant reduction in farmers' incomes [14].

76% of the area planted under mango in Ghana is owned by members of farmer-based organizations (FBOs) and unorganized individual farmers [12]. However, compared to commercial farms, the yields of small- and medium-scale farmers tend to be low, sometimes unsustainably so – larger farms achieve yields of up to 189 fruits per tree, while smaller farms usually average less than 80. There is thus much scope for farmers in the mango value chain to increase their income, both by increasing yields and by reducing PHL. equation for participants only, the treatment effect model analyses outcome data for both participants and non-participants. In addition, the treatment effect model is intended for program evaluation, while the sample selection model focuses on selection bias.

Figure 4. Mango losses across the value chain in Kenya – adapted from [13]



This would have positive repercussions for the entire value chain, as traders and processors would gain access to higher volumes of fruit at lower prices, increasing their competitiveness in both domestic and export markets. A case study of the mango supply chain commissioned by the Rockefeller Foundation found that access to a consistent supply, in terms of both quality and quantity, is the primary challenge faced by multi-national corporations interested in expanding their market in sub-Saharan Africa [13]. Constraints at every stage of the value chain contribute to the problem, including poor harvesting techniques, limited market linkages, and lack of access to appropriate processing equipment.

A study of mango post-harvest loss in Ethiopia—another country that shares similar geo-climatic conditions and agricultural practices as Ghana— found that practices known to increase PHL, such as allowing ripe mangoes to fall from the tree, and packaging them in non-ventilated sacks, are very common [14]. The study also found that refrigerated transportation and cold storage facilities are very rare and that over-ripening of the produce is a common problem. Providing producers with access to cooling technologies could be one of the most important first steps to upgrading the mango value chain and reducing losses [14].

Tomatoes

Fresh tomato and concentrated tomato paste are staples of the West African diet and a major source of income for smallholders involved in commercial farming. In 2014, Ghana produced 366,772 tonnes of fresh tomato, with 90% of local production consumed locally [15]. Smallholder production predominates, with more than 90,000 farmers growing the crop and over 300,000 people involved in wholesale and retail trade [16]. To fulfill demand not met by local production, Ghana is estimated to import up to 84,000 tonnes of fresh tomatoes from its neighbors. Despite its potential to meet its local demand as well as expand into export markets, Ghana's performance in the tomato industry in the recent times has been below its potential, the effect of which is acutely felt by thousands of smallholder farmers [17].

The tomato supply chain incurs some of the highest post-harvest losses in the fruit and vegetable supply chains in Africa. A conservative estimate of PHL in tomatoes across SSA, including Ghana, is around 10%; this translates to a value of approximately USD 20 million [18]. One study estimates tomato loss in Ghana to be as high as 30% [19]. The challenges faced by smallholder tomato producers are similar across SSA. Common causes of post-harvest loss from production to marketing are listed in Table 2.

Table 2. Prevalent causes of PHL in tomato supply chains in SSA; adapted from [18]

Stage in supply chain	Cause of loss
Production and harvesting conditions	• Water quality • Insufficient or too much pesticide use • Lack of information on market quality standards
Transportation	• Lack of access to adequate transportation – farmers are forced to harvest at a later stage of ripening and sell to nearby consumers • Poor road conditions result in tomatoes experiencing vibrations that impact shelf-life
Handling and Packaging	• Rough handling by field workers • Improper stacking and packaging of fruit • Large baskets and sacks with rough lining: pressure and perforations result in mechanical damage
Storage	• Shortage/lack of cool chain facilities (also in transportation vehicles)
Marketing	• Poor market sanitary conditions • Inability of smallholder producers to meet global standards and market requirements

Poor handling of tomatoes and transport-related damage; in addition, a lack of adequate transport infrastructure constrains smallholder farmers by limiting their accessibility to markets. For example, tomato losses in Limpopo, South Africa were found to mostly result from poor road conditions and over-ripeness. In Nigeria, losses were attributed to improper packaging and stacking/arranging of the tomatoes during transport and high temperatures in trucks. The use of traditional baskets for tomato storage and transportation is common across SSA, including in Nigeria, Tanzania, Ghana, and Kenya. This compromises the quality of a large proportion of the tomatoes: those that are at the bottom of the basket are under pressure and tend to degrade faster. Plastic containers and cartons used by smallholder farmers in South Africa are similarly not designed for protecting tomatoes, and also lead to high levels of loss [18].

Handling, packaging and transport practices for tomatoes depend on the market for which they are destined. Tomatoes destined for supermarkets have a much better developed post-harvest management system, using appropriate packaging, storage, and transportation in cold-chains. Informal traders who source directly from farmers do not have access to such systems, relying rather on makeshift packaging, storage, and transportation technologies. In addition to damaging the product, these improper practices also increase the risk of food safety hazards [18].

4. INTERVENTIONS THAT WORK

When evaluating the potential for a particular technology or approach it is important to consider both the characteristics of the user of that technology, and the context in which the user operates. For instance, some technologies may be difficult to acquire, use, and manage for smallholder farmers, and may not prove to be cost-effective over time; the same technology however may prove to be of value to large-scale growers.

Post-harvest losses of perishable fruit and vegetables can be addressed at different stages of the value chain, as summarized in Table 3. Considerations of crop type and variety are important, as these factors will affect the product's perishability and storage potential [20]. While many technologies exist to reduce losses from harvest onward, innovations to reduce PHL can start before the farm-level with the development of varieties that have longer shelf-lives while maintaining their nutritious properties, taste, and texture. As further described in Section 3, coordination across the value chain in the deployment of new technologies and approaches is also essential. Capacity development and training of specific actors along the chain, starting with farmers, is another important need, as is linking different actors to the appropriate markets [21].

Table 3. PHL reduction strategies for fruit and vegetables, adapted from [20]

Harvesting	Careful handling during harvest to reduce bruising, scratching and punctures; harvesting during the cooler hours of the day (e.g. the early morning); shading crops once harvested
Handling	Protecting the crops from injury can minimize pest attacks and physiological and dehydration damage.
Sorting and Cleaning	Sorting and cleaning can increase shelf-life considerably. By separating higher and lower quality crops, the risk that fungi or bacteria spread form damaged crops to others is reduced. Quality parameters like size and color can be determined through the use of visual charts, and allows the crops to be targeted to appropriate markets to maximize revenue.
Packaging	Proper packaging to maintain freshness prevents quality deterioration as well as acting protecting against physical damage during transportation. Clean, smooth and ventilated containers are key, but the specific type depends on the crop.
Transportation	Use of clean, cool, ventilated and covered vehicles for the transport of perishable crops, with transport during the colder hours of the day advised. The smoothness of the road is also important as excessive vibrations and movement can degrade crop quality. Avoid watering the produce before transport as this increases decay. Care during loading and unloading is a simple yet effective way to reduce loss.
Storage	Only crops that meet specific quality standards should be stored (correct level of maturity, undamaged). Optimal temperatures for each commodity should be known and used as shelf-life is longer when stored in optimal temperature conditions.
Processing	Processing allows producers to stabilize the produce, diversify the food supply for enhanced nutrition throughout the year, and generates employment. Drying, salting, fermenting and pickling are among the simpler processing technologies.

Examples of low-cost technologies

A review of 12 international horticultural projects implemented in developing countries aimed to assess the effectiveness of different low-cost postharvest technologies; these technologies are summarized in Table 4 [22]. Through a series of cost-benefit analyses and assessment of field trials, the review identified many promising small-scale innovations that reduced postharvest losses and improved returns to farmers by at least 30 percent. Of the 32 technologies assessed and field-tested and for which cost-benefit analyses were performed, 21 were found to be profitable; 17 of these increased farmers' incomes by up to 33 percent. However, in field tests, these technologies were found to be under-utilized; simpler, cheaper technologies that fit in with the existing value chain and marketing system were found to have a higher adoption rate and were more sustainable in the long term in the current context. Examples of the technologies that were tested and analyzed include:

i. Improved containers and packaging: Liners

A field trial in India found that the use of locally produced and inexpensive light-weight fiber-board (CFB) liners for plastic crates reduced bruising of fruit. Guavas transported in non-lined crates had 12.5 percent more bruises than those transported in the CFB-lined crates. The value of the bruised guava fell by over 60%, while 50 sets of liners cost USD 7.4. A simple cost-benefit analysis reveals that for each 1MT load of guava (50 crates) transported with liners, additional profits amounted to USD 40, which is over five times the amount of the initial investment. The liners can be reused several times and are recyclable.

ii. Improved containers and packaging: Smaller sized packages

In Ghana, sacks half the size of the usual sacks used for packaging cabbage were field-tested for handling and transport. The larger sacks hold up to 70Kg of cabbage, while the smaller ones hold around 30kg. The smaller sacks result in 77% of the initial volume of the cabbage being available for sale, compared to 68% available for sale with larger sacks. Accounting for the costs of the sacks—USD 0.75 for the smaller sack and USD 1.00 for the larger sack—a 1MT load that uses smaller sacks will generate USD 83 more than the larger sacks.

iii. Field packing under thatched roof structures and concrete flooring

A field trial in Rwanda tested a field packing station on a vegetable farm near Kigali. Typically, mixed vegetables are packed in traditional woven baskets and are sold the day of harvest to intermediaries who transport the produce to market. Using the packing station, tomatoes were sorted, graded, and packed into plastic crates under shaded conditions. The shade resulted in 2 percent lower water losses, while the grading and sorting allowed farmers to sell the tomatoes for higher unit prices. The cost-benefit analysis revealed that the initial investment of USD 1,161 in the packing station would be paid off after six uses, and its use for each additional MT would generate additional profits of USD 198.

Table 4. Low-cost technologies for the reduction of PHL in horticultural value chains in developing countries, adapted from [22]

Cause of PHL or loss in value of commodity	Technology	Effects of the technology	Profit potential and examples
Wilting and weight loss of produce	Shade at field level: cloth shade structures for tomatoes	Reduce field-heat and sun-induced physiological damage/wilting; cooler temperature by 6-10°	$30/200kg
Mechanical damage during marketing	Plastic crates, liners for containers, smaller containers	Reduced damage by 30-60% Improved market value by 40-140%	Plastic crates for tomatoes in Cape Verde: $40/200kg Crate liners for Guava in India: $56/1000kg Smaller sacks for cabbages in Ghana: $83/1000kg
Bad appearance due to damage = lower value	Proper harvesting, sorting/grading and packaging practices along the value chain	Field packing of tomatoes reduced losses Improved market value from 50-100%	Tomatoes in Rwanda $198/1000kg
High temperatures in the value chain speed up degradation of the produce	Short term storage in 'Zero Energy Cool Chambers' for fruits and vegetables	Temperatures reduced to 5-10°C Depending on crop, increases shelf life by days or weeks Reduces weight losses and losses overall	Vegetables in India: $140-390/1000kg Cabbage in Ghana: $58/200kg
Market price fluctuation based on supply and harvesting time	Low-cost cold rooms for storage: CoolBot-equipped on farm storage	Reduce temperature to 2° Increase shelf-life for 4-8 months Reduce losses to less than 5%	Onions in Ghana: $8790/6MT Potatoes in India: $$1296/6MT

Lowest market value during peak harvest period	**Solar drying of fruits and vegetables** **Canning or bottling of processed tomato products**	**More stable produce, easily stored** **Reduces losses to less than 2%** **Longer shelf life (up to one year)** **Improved market value**	**Solar drying of chili peppers in Benin: $15/15kg** **Tomato concentrate in India: $3/100kg**

iv. Zero Energy Cool Chamber (ZECC)

A field trial in India tested the effectiveness of cool chamber storage units for temporary storage of 100 kg of mixed vegetables. These were constructed with bricks and sand and were saturated with water to promote evaporative cooling; the units were tested in various locations. Weight losses were reduced by 20 percent and vegetable shelf-life increased from one day to between five and six days.

A similar field test of ZECC in Ghana showed that the produce available for sale increased to 62 percent of the original harvest, compared to 42 percent without a cooling chamber. The higher humidity and lower temperature maintained in the chamber helped the produce retain water and maintain their weight and visual appearance. After paying off the initial investment of (USD 813 – USD 1040) over 18 uses, the technology provided an additional profit of USD 58 for every 200kg of produce, compared to traditional practices without ZECC systems or immediate sale.

v. Small-scale cold room with CoolBot Control unit

CoolBot uses air-conditioning units to maintain very low temperatures and high levels of humidity within insulated rooms. In Ghana, a field trial for onions compared the CoolBot system to storage inside traditional sheds. Onion losses were reduced from 30 percent to 5 percent using the CoolBot system, and the market value increased by USD 0.50/kg for onions sold immediately after harvest and by USD 2/kg for onions stored and sold after four months. Driven by the higher value of the produce off-season, the technology is immediately profitable if a reliable power source is available. Even if a back-up 3.5 kW generator is required, the total cost is offset after two to three years of use.

5. ECONOMIC AND BEHAVIORAL FACTORS[2]

Much of the discussion around PHL is centered on identifying best practices and technologies, and how to effectively provide information and technologies to farmers. However, to ensure that these practices and technologies are adopted, policy makers must also take into account economic and behavioral factors that influence farmers' decision making. Three key bottlenecks to adoption are discussed below, which highlight the need to factor in farmers' economic constraints and behavioral biases when designing policy interventions to mitigate post-harvest loss, followed by potential design solutions.

[2] This section is adapted from [23].

i. Risk aversion

While technologies for the prevention of PHL are designed to reduce the risk that farmers lose the value of their crops after harvest, from perspective of a farmer who has no direct experience with a technology and may not fully understand its benefits, such investments are risky. The poorer the farmer, the more risk-averse she is likely to be, since the consequences of spending limited resources unwisely are more severe.

Potential design solution

Reduce the degree of risk associated with the purchase: Post-harvest technologies could be sold with a money-back guarantee. If farmers are unsatisfied with their purchase, or if they can show evidence of product failure (for example of pest damage to hermetic storage bags) they could return these items for a full or partial refund.

ii. Timing of cash availability and need for technology

Smallholder farmers typically lack access to formal vehicles for savings and credit. This can make it difficult to invest in technologies that will yield benefits in the long term. One study in Tanzania found that when farmers were introduced to the concept of post-harvest loss in cereal crops and hermetic bags known to prevent PHL in a cost-effective manner, many expressed an intention to begin using hermetic bags for storage [23]. Yet most of them did not procure these bags early enough. When harvest time came, farmers had very little cash on hand and could not afford the bags. After crops had been sold and farmers were again flush with cash, crop storage was no longer a priority and as a result, they still failed to purchase improved bags.

Potential design solution

Establish a layaway program that breaks the cost of procuring technology into manageable sums: In the case of hermetic bags, at the start of the growing season, farmers would commit to purchasing a certain number of bags. On a periodic basis (bi-weekly or monthly), they would pay a fraction of the total cost to either the leaders of the farmers' association or to the staff of a participating non-profit and pay off the entire cost by harvest time. This would not only make the cost of technology more manageable, but also reduce the time between forming an intention to adopt technology and acting on that intention.

iii. Over-valuing the present

People are less willing to lose in the present, even though that loss may translate into a higher value gain in the future. In other words, people value $5 today more than $5 tomorrow, or even a higher amount later in the future. This universal tendency, which behavioral scientists term "present bias", has important implications for the adoption of recommended practices that come at a cost but yield benefits later. In Tanzania, the upfront cost of hermetic bags is five times greater than the cost of standard polypropylene bags. In the medium to long run, farmers will almost certainly benefit from switching to hermetic bags, which dramatically reduce losses to pests; but the investment may only pay off after the second or third year of usage. In the short run, farmers must bear the loss, which is more immediately felt and thus valued more. The problem is exacerbated by the fact that many farmers have limited education and are not well-equipped to weigh the costs and benefits of the options at hand.

Potential design solution

Make the long-term benefits of a technology salient: A tag with cost-benefit information could be affixed to post-harvest equipment or distributed as a flyer wherever these are sold. Information on the costs and benefits per year would focus attention on payoffs, and make the payoffs to adoption clear.

6. INSTITUTIONAL FACTORS: MARKET COORDINATION, LEADERSHIP, AND INFRASTRUCTURE

Coordination within and across stages in the value chain is critical for the reduction of post-harvest loss. Many post-harvest technologies are only cost-effective at a level of scale beyond that of the typical smallholder farmer. Farmer organizations and other institutions for the aggregation of produce from smallholders thus have an important role to play in improving postharvest management, as they can allow farmers to access technologies (such as storage, packaging, and transportation facilities) that would otherwise be inaccessible.

Vertical coordination across the different stages of the value chain is similarly critical, as targeting only a specific node may simply shift of losses from one node to another, erasing any incentives for adoption of new technologies and practices. Reduction of PHL thus depends on the simultaneous mobilization of the key actors. For example, reducing the loss of perishable products at harvest has little value to farmers if they are not able to get their crops to market quickly. Further, smallholders must be able to meet specific quality and safety standards to access high value downstream markets that value the preservation of crop quality. This requires awareness of what those quality standards are and how they can be achieved, as well as access to the technologies required to meet them [24] [18]. Both awareness of and access to technologies can be facilitated by linkages with buyers, which are in turn facilitated by coordination of farmers in groups. Redirecting would-be losses to lower-end food markets or non-food industries such as those for feed or bio-energy can also reduce the overall economic value and extent of natural resources wasted. Identifying and developing such alternatives is crucial for more efficient management of PHL [24].

When production is highly concentrated among a small number of farmers within a small geographical area, as is the case for many horticultural crops in Ghana, including carrots, French beans, macadamia nuts, and oranges, incentives may exist for the private sector to invest in making value chains more efficient. However, this is not the case for crops that are grown by a larger number of farmers; reducing PHL for such crops would likely require a more government-led approach [25].

An assessment by Deloitte and the Rockefeller Foundation concluded that contract farming in SSA increases farmers' income and reduces post-harvest losses, especially when applied to the value chains of high-value, high-margin crops including fruits and vegetables [26]. These value chains offer good incentives for the significant capital investment required by off-takers. The large agricultural businesses engaged in contract farming typically operate collection centers for the organized aggregation of produce, and ensure appropriate handling, storage, and transportation practices, as they must adhere to strict process and product quality requirements imposed by their buyers. Most of the time, these types of arrangements are for crops destined for the export market. Reproducing this model for domestic markets could decrease PHL while potentially improving the income of farmers and increasing availability of nutritious food for domestic consumers [26].

Where the private sector lacks sufficient capacity or incentives for investment in PHL reduction, public sector and non-profit actors can facilitate coordination among value chain actors and leverage the private incentives that do exist. Public-private partnerships may include training and capacity building, and implementation of certification and standards [21]. An example of a private-non-profit partnership to reduce PHL is Coca Cola's and the Gates' Foundation investment in the mango value chain in Kenya. To meet targets for local sourcing associated with its corporate social responsibility goals, Coca Cola sought to increase its procurement of Kenyan mangoes. To achieve this, the company invested in different stages of the mango value chain, with partial funding from the Gates Foundation. The investment included providing a local processor with recipes and marketing training, as well as technical assistance to meet Coca Cola's strict quality and food safety standards. Through an NGO, farmers were trained on improving yields and reducing losses during and immediately after harvest, while links to traders were facilitated through the creation of farmer cooperatives to aggregate output. According to an assessment by the Rockefeller Foundation, the intervention reduced post-harvest losses by almost by 50 percent, while production was doubled. However, losses remain a challenge, still reaching 30 percent of production post-intervention [13].

A critical role for the public sector in the reduction of post-harvest losses is the provision of quality transportation infrastructure and electrification. Good roads directly reduce post-harvest loss by cutting down the time it takes to reach markets and by lessening damage in transit. Access to electricity dramatically reduces the cost of cold storage, increasing farmers' ability to access that important technology. In addition, high-quality infrastructure may increase returns to private investment in other technologies for the reduction of post-harvest loss.

Finally, gender has often been overlooked in PHL research. In many cases, post-harvest systems underperform because women, who play key roles in post-harvest management, lack the capacity, knowledge, and means to access and use technologies and services. By and large, this is due to ingrained gender inequalities that are costly and inefficient [3]. Efforts to reduce these inequalities should be institutionalized by both the government and private sector actors.

7. CONCLUSIONS AND RECOMMENDATIONS

• Horticulture is an important sub-sector of Ghana's agricultural economy with great potential for growth due to a strong export market as well as growing domestic demand. Given that PHL in horticultural crops is particularly acute, returns to PHL prevention in horticulture are expected to be high.

• Numerous low-cost and cost-effective postharvest technologies to prevent PHL exist. There are, however, multiple material and behavioral bottlenecks to adoption, such as lack of knowledge and information about such technologies, credit constraints to acquire them, and farmers prioritizing present consumption over future income. Interventions should be designed keeping in mind both material and behavioral constraints.

• Some technologies and interventions may only be cost-effective at scale or when used collectively rather than by individual farmers; achieving such scale or coordination requires active collaboration and investment by public and/or private institutions.

• Efforts to address PHL must consider the entire value chain rather than focus on losses at a single stage.

• The private sector should be encouraged to invest in making value chains more efficient, particularly when production is highly concentrated so that firms are able to capture a return on these investments.

• Ghana should study instances of regional successes and create enabling conditions for partnerships across the private and non-profit or public sector, such as that between Coca Cola and the Gates Foundation in the mango value chain in Kenya.

• For crops grown by many, geographically dispersed farmers, reducing PHL will require leadership by the public sector.

• Investments outside of the agri-food sector, including transportation infrastructure, rural electrification, and the development of rural financial markets can reduce PHL while providing broader socio-economic benefits. All of these benefits should be taken in to account when considering such investments.

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