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The YieldWise Approach to Post-Harvest Loss Reduction: Creating Market-Driven Supply Chains to Support Sustained Technology Adoption

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Abstract: Excessively high levels of post-harvest loss often are a feature of agricultural systems dominated by small-holder farmers. However, this situation is something of a paradox, as technologies exist that have been shown in field demonstrations to substantially reduce post-harvest loss. What explains this paradox? Building on insights derived from the Rockefeller Foundation's YieldWise Initiative, this article proposes that while reducing post-harvest loss generally does require technology adoption by small-holder farmers, market-driven supply chains are essential to the sustained use of those technologies. We illustrate this approach using in-depth interview data collected from the YieldWise participants belonging to the Iringa Hope Cooperative in Tanzania. Data on the benefits and challenges of such an approach are provided from the perspective of the small-holder farmer. In addition, we model the economic benefits associated with this approach.

Keywords: post-harvest loss reduction; the YieldWise initiative; economic comparisons; small-holder farmer perspectives

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1. Introduction

Agriculture and its supporting food systems serve society by striving to achieve multi-dimensional goals. A key goal is the provision of abundant amounts of safe, nutritious, and inexpensive food with minimal detrimental impact to natural systems. However, it is estimated that approximately 800 million of the world's people faced hunger in 2020—roughly one person in ten [1].

At the same time, it is widely recognized that large amounts of the food produced worldwide are not consumed; the Food and Agricultural Organization (FAO) estimates that 30–40% of agricultural production is lost because of a combination of post-harvest loss (PHL) and food waste [2]. Indeed, Sustainable Development Goal 12.3 [2] expresses a commitment to halve food waste at the retail and consumer level, including food loss across supply chains. It is estimated that food waste comprises 17% and post-harvest loss 13% of agricultural production [2]. Those relationships between food waste and food loss are consistent with estimates reported by Gustavsson et.al [3] in the FAO report, which was a key catalyst in sparking renewed societal interest in reducing food loss and waste.

A significant portion of PHL in sub-Saharan Africa and Asia is associated with a lack of infrastructure among the small-holder farmers (SHF) who manage 80% of the farmland there [4]. In addition to contributing to food insecurity and hunger, PHL also has detrimental effects on the environment and the incomes of the majority of the population that rely on agriculture for their livelihoods [5].

This paper addresses a key issue relating to the challenge of reducing post-harvest loss in the small-holder farming sector. That issue is the stubborn persistence of high levels of loss at the small-holder farmer (SHF) level, even though practical tools and practices that can significantly mitigate losses exist. Further, such tools and practices have been repeatedly shown to be effective and economic in pilot tests conducted in small-farmer settings. However, widespread adoption typically does not follow the pilot project successes. The common expression: Pilot projects never fail, pilot projects never scale, illustrates this phenomenon [6].

Spurred by the global food crises of 2008–2012, the Rockefeller Foundation initiated the YieldWise program in Africa to reduce food loss. The YieldWise program had a primary intent of improving SHF well-being as an outcome associated with reducing PHL. However, the YieldWise structure and formulation were distinctive in explicitly recognizing that achieving PHL reduction involved key elements of the surrounding agricultural ecosystem. This recognition is a contrast with the more common approach of concentrating on practices conducted only on the farm [7]. Lessons learned from YieldWise activities in Tanzania will provide a lens into both the challenges and opportunities of establishing processes that strive to achieve sustained post-harvest loss (PHL) reduction.

The remainder of this article comprises the following sections. First, the notion of stubborn persistence of PHL as a societal concern will be reviewed. Second, the YieldWise experience will be considered in the context of its goals to achieve sustained PHL reduction. The overall structure and intent of YieldWise will first be reviewed. Then, responses of SHFs to the program and an economic illustration in a local region in Tanzania will be presented. Conclusions and implications are provided in the final section of the paper.

2. Post-Harvest Loss Reduction: No Quick Fix

The world seemingly "discovered" post-harvest loss as a key societal issue during and after the global food crises of the late 2000s. However, as is often the case, that discovery was only a "rediscovery". As far back as the 1970s, global institutions were concerned with adequate food supplies and, in 1974, the United Nations held a World Food Summit in Rome [8]. In that 1975 conference, the then US secretary of state, Henry Kissinger, made an impassioned plea emphasizing the need for global efforts to reduce PHL. Following this call to action, the UN General Assembly adopted a resolution calling for at least a 50% reduction within ten years [9]. However, more than 40 years later, many developing countries still struggle to find sustainable solutions to mitigate PHL of cereals, grains, fruits, and vegetables.

2.1. A Post-Harvest Loss Paradox

In developing countries, today, PHL routinely exists at excessive levels, resulting in reduced well-being of smallholder farmers, diminished food security, and unnecessary environmental degradation. While not new, the problem is stubbornly persistent; even though:

- Technologies are available that can effectively reduce post-harvest loss [10,11].
- Although unfamiliar where post-harvest loss levels are high, available technologies generally require "low-tech" skills to directly apply.
- Analyses of pilot projects routinely report that significant economic benefits can be achieved with the use of PHL-reducing technologies.

This PHL paradox [12] often is framed as farmers "failing to adopt" technology. This framing reflects a view that pilot demonstrations, which rely on external resources and support but take place in specific limited settings, will be replicated by SHFs in the context of their day-to-day lives.

Instead, we posit that effectively managing PHL should be framed as a market development opportunity, and not just as a technical problem. Although the introduction of a technology novel to the area often is a necessary and difficult step, demonstrating that the technology works in a pilot setting is generally insufficient. We argue that sustained success is likely to be achieved only when an organically self-sustaining market-based supply chain for the technology is established. Such self-sustaining market-based supply chains provide and enhance the technology, as well as generate value for the farmer, market chain participants and consumers.

The following two figures illustrate this idea. Figure 1 depicts a pilot effort focused on demonstrating that the intervention technologies will work, in terms of reducing PHL in the field.

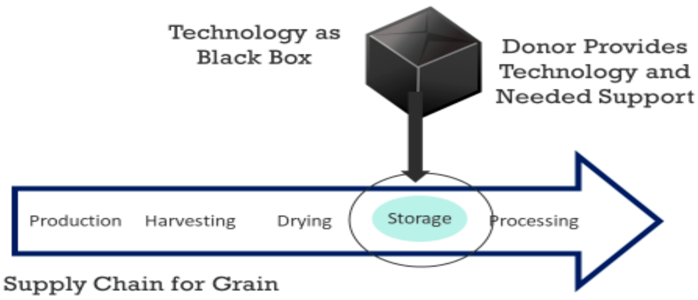

Figure 1. Intervention to demonstrate that a technology will "work"—its use will reduce PHL.

In Figure 1, the horizontal bar depicts the supply chain of an agricultural commodity, for example, maize. That chain extends from farm production to processing. As an example, let us assume that the intervention is focused on improving storage at the smallholder farmer level. This could be done through use of hermetic storage bags, small metal silos in the farm household, or community storage systems. All of these approaches can work.

In the pilot project context, the technologies needed are provided by the donor (or donors) as a package to be tested and adopted. This is depicted in Figure 1 as a black box. In addition to technology, the project likely will provide education, support, and service for the technology under study. Costs are at least partially subsidized for the technology, and routinely for the supporting factors.

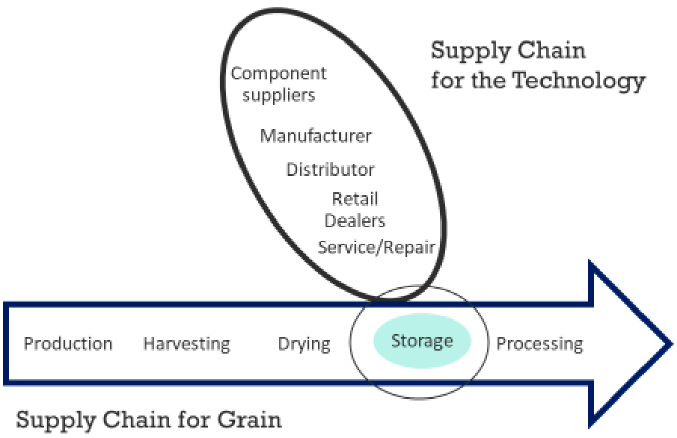

Figure 2. Structure of a technology supply chain to support sustained adoption.

The work required to introduce and test technologies and practices in the field is difficult and requires considerable dedicated effort. The comments offered here are not intended to downplay these immense contributions. Rather, our intent is to show that the success of the pilot project cannot be assumed to predict that similar success will be attained in the day-to-day reality of the SHF. Without such success sustained, scaled technology adoption will not be achieved.

In Figure 2, the "black box" of Figure 1 is replaced with a vertical graphic depicting components of a supply chain for the technology of interest. Now there are *TWO* supply chains: one for the agricultural commodity, maize, and one for the technology that enables improved storage (e.g., bags, silos, or community storage). Significantly, the components of the technology supply chain include more than just the physical elements of production and delivery. For example, marketplace mechanisms such as training, user support, and retail-provided financing are a component of supply chain service function. These mechanisms are vital to support sustained, scaled adoption.

To sharpen the distinction, let us compare the two types of pilot efforts. If successful, one demonstrates that the particular technology can reduce PHL. A key question is, what happens after the pilot project successfully ends? For the first, the black box of technology and service disappears. For the second, actors along the vertical supply chain have a natural incentive to expand adoption and to improve the technologies needed for PHL reduction.

2.2. Why Does the Market Not Handle This?

It is natural to expect private sector entities to enter markets where pilot efforts have demonstrated that technology use can be profitable. However, in many developing country settings, especially in rural areas, such institutions tend not to be strong. For example, formal credit mechanisms may not exist or may be difficult to access. Additionally, enforcement of contracts can be uncertain, restricting the entrepreneur's ability to access supplies and services.

The term "institutional void" often is used to identify such deficiencies [13]. In rural areas, it is common for those capabilities to be inadequate. The result is that the strong, vibrant ecosystem needed to foster the establishment and growth of business innovation is lacking.

2.3. Interventions Demonstrating the Potential for Success

This section focuses on redefining success for interventions aspiring to reduce PHL in developing country agriculture. An important first step for such an effort often is a pilot effort to verify and demonstrate to SHFs that the technology can reduce PHL in their setting. From an economic perspective, this step is important to document that demand may exist. However, that step, by itself, often is insufficient. It also is necessary that an effective system for on-going supply of the technology be available or established. An effective market-based supply chain can accomplish more than simply physical distribution. The marketing, support, and development functions of a well-functioning supply chain provide the impetus to foster sustained and scaled adoption of the technology.

Below, brief descriptions describe two successful PHL-reducing interventions that support the notion that PHL reduction in small-holder farming can be achieved.

2.3.1. Postcosecha Program: Metal Silos in Central America

The Postcosecha Program showcases the importance of building a market environment to drive successful adoption of the metal silo technology. Over a 20-year period, the Swiss Agency for Development and Cooperation (SDC) fostered the demand for metal silos as a PHL-reducing technology. It actively engaged public and private stakeholders to promote the value of metal silos. Direct economic benefits to farmers drove continued adoption. On average, SHFs who used metal silos received higher prices and gained 23% higher revenues than non-adopting farmers. As a result, approximately 670,000 metal silos were put to use by smallholder farmers in Honduras, Guatemala, Nicaragua, and El Salvador. Metal silos helped 415,000 rural households preserve about 380,000 tons of grain each year, the equivalent of about 1/5 of the annual grain production in the four countries [14]. Buoyed by that success, the program was extended to other countries in Central America and Africa [15,16]. Importantly, the program also assisted in establishing a system to supply metal silos. The SDC trained more than 2000 tinsmiths in production, distribution, and marketing [14]. Trained tinsmiths were able to start their own metal silo businesses. The future supply of metal silos was thus secured [17].

2.3.2. PICS Project: Triple-Layer Bags in Africa

The Purdue Improved Cowpea Storage (PICS) project is an excellent example of the importance of the supply chain in a development project [18]. This initiative illustrates the importance of addressing multiple links in the chain, as well as adapting to the local context. The PICS project originated at Purdue University in the United States, with the goal of protecting stored cowpea from pest damage with limited use of insecticides. PICS bags have been well-received in Africa. Within a five-year period, over 2 million bags were sold across 10 countries, 1.7 million households were reached, and the regional internal rate of return (IRR) was about 29% [19]. These results were driven by the bags' cost-effectiveness, high returns on storage, and perceived benefits to income and health. Developing an effective supply chain, with coordinated communication, marketing, and extension activities, was a major factor in the success of the project [19].

2.3.3. The Role of Institutional Voids

The presence of institutional voids provides at least a partial explanation for the existence of the PHL paradox. Inadequacies in the institutions surrounding the relevant market potential can impede sustained implementation. For both programs just described, effective collaboration among the social, private, and public sectors was important to achieving positive outcomes. The catalytic role played by the social sector in circumventing key institutional voids should not be overlooked. Sustained success was achievable when the capabilities of a market-driven supply chain were supported by public, social and private forces.

3. The YieldWise Initiative in Tanzania

Figure 3 depicts the pattern of food price changes as documented by the Food and Agricultural Organization within the United Nations in both nominal and real terms from the 1960s thru the 2020s [20]. (Nominal prices are the current prices in the market for the year noted. Real prices are adjusted for inflation relative to a base period; 2014 to 2016 in Figure 3). The figure's vertical axis is an index where 100 is fixed at the base period. The horizontal axis presents time from the year 1961 to 2023. The data presented are of particular interest during three periods. The first occurred in the early to mid-1970s when the Arab Oil embargo and crop shortfalls in certain regions led to a 50% increase in real prices between 1973 and 1975 [20]. The second message from Figure 3 is that the relatively short-run rise in prices was followed by three decades of relatively low and stable food prices, actually declining in real terms. Therefore, it is not surprising that the sudden and dramatic 40% increase in food prices between 2006 and 2011 was the focus of considerable global concern [20]. Fueled again by crop shortfalls in important regions and exacerbated by currency fluctuations tied to monetary uncertainties associated with the Great Recession experience, these food price increases fueled protests and government uncertainty in developing countries.

International agencies, national governments, the private sector and civil society organizations brought attention to these sharp increases in food prices. One illustration of this attention is the New Vision for Agriculture crafted by members of the World Economic Forum [21]. Embedded within this vision is the belief that global agriculture must simultaneously strive to deliver food security, environmental sustainability, and economic opportunity. Defined in 2008, the New Vison ambitiously calls for a 20% improvement per decade until 2050. Its five operating principles are (1) mobilize the private sector, (2) employ market-based solutions, (3) empower farmers and entrepreneurs, (4) integrate interventions to achieve momentum and scale, and (5) collaborate with diverse stakeholders to build strengths and distribute risks.

Recognizing this same set of global challenges and opportunities, the Rockefeller Foundation undertook an extensive learning journey focused on identifying causal factors and potential interventions that could lessen the tragic impacts of food shortages and high food prices on the world's poor. At about this same time, information indicating the existence of unacceptably high levels food waste and post-harvest loss began to attract global attention [3]. The YieldWise Initiative was the product of that learning journey. That undertaking incorporated an innovative, systemic approach to the process of reducing post-harvest loss.

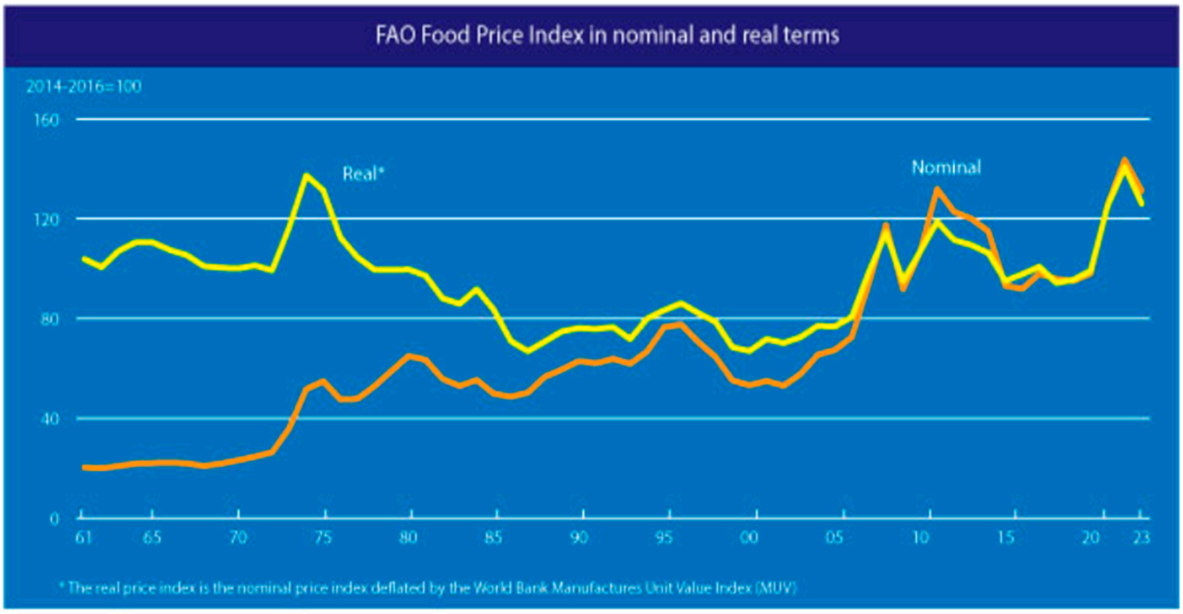

Figure 3. FAO Food Price Index in Nominal and Real Terms [20].

The YieldWise Initiative emphasized post-harvest loss reduction as a complex problem, where technologies new to a particular locale would be needed but likely would not be sufficient to achieve sustained loss reduction [22]. Markets around the world are affected by a complicated set of competing and interacting forces. In developing country agriculture, markets are further constrained by fragmented supply chains for inputs and for the output from farms. Further, physical infrastructure generally is sub-standard. In general, however, historic interventions to reduce PHL tended to focus on reducing loss at a single component of the supply chain.

The YieldWise Initiative was structured with four key components [23]:

- Access to technologies: promoting the adoption of appropriate loss-reducing technologies.
- Access to finance: collaborating with financial institutions to develop credit products that can be accessed by farmers and farmer-based organizations.
- Aggregation and training: training farmers and other supply chain actors in post-harvest management and facilitating development of local aggregation centers.
- Access to markets: stimulating demand by engaging actors across the diverse ecosystem of buyers.

With the goal of providing catalytic impetus to PHL-reducing interventions, YieldWise focused its operations on three commodity types in three countries. The three combinations were maize in Tanzania, mangos in Kenya, and tomatoes in Nigeria.

3.1. YieldWise at the Country Level

This section provides insights regarding YieldWise in Tanzania along three dimensions. First, country-level activities and outcomes are reported. While such macro level impacts are important, this section's latter two segments emphasize effects at the SHF level. Both of the efforts described there benefitted from involvement and support of leaders, staff, and SHF members of the Iringa Hope cooperative (described later). This section's second segment describes SHF observations as reported by Iringa Hope members who participated in the YieldWise program. The section's last segment reports on an economic analysis that compares the effect of reducing PHL in isolation versus outcomes when PHL-reducing efforts are integrated within a more comprehensive set of improvements.

In 2016, the Rockefeller Foundation launched YieldWise Food Loss—focused on reducing food loss of fruits, vegetables, and staple crops in Kenya, Nigeria, and Tanzania, countries where up to half of all food grown is lost [23]. This discussion will focus on the YieldWise experience to date for maize in Tanzania.

Starting in 2016, the Alliance for a Green Revolution in Africa (AGRA) served as the primary implementing agent for the YieldWise initiative in Tanzania [24]. Supported by its headquarters in Dar Es Salaam, AGRA worked with numerous implementing partners and other collaborating entities to deliver the benefits of the YieldWise effort directly to SHFs. Project goals included reducing PHL by at least 50% and increasing SHF incomes by 25%. Within Tanzania, the regions targeted included Iringa and Njombe, Mbeya, Ruvuma, Arusha, Kilimanjaro, and Manyara.

A food staple in Tanzania, maize is cultivated by most farmers to ensure both household food sufficiency and for commercial purposes [25]. Illustrating this importance, maize occupies nearly half of the country's cropland, with Tanzania being East Africa's largest maize producer. Maize stored in traditional storage in Africa chronically suffers from high levels of post-harvest loss. For example, in Benin, estimated quantity losses after six months of storage ranged from 17% to 40% of total maize production [26,27]. Similarly, [28] conducted a careful examination of losses on farms when traditional storage techniques were employed. After only 30 days of storage, losses exceeding 20 percent were observed in both Uganda and Burkina Faso. After 90 days, loss estimates of 59 and 54 percent were recorded in Uganda and Burkina Faso, respectively.

Starting in 2016, the YieldWise Initiative introduced SHFs to a series of post-harvest loss-reducing technologies. By the end of that year, more than 25,000 SHFs in Tanzania had been trained in the use of at least one of these technologies [24,29]. They included:

- Mechanized dehusking
- Mechanized threshing
- Tarpaulin use
- Improved storage practices. Prior to implementation of YieldWise, the use of the target technologies had been quite limited. By mid-2017, a strong increase in technology application was noted:The use of mechanical dehusking almost doubled, reaching an adoption rate of 24% among beneficiary farmers.
- The use of threshing technologies increased significantly, with about 43% of farmers using the technology.
- From the start of the YieldWise program to mid-2017, the utilization of tarpaulins for sun drying increased to 88% among beneficiary farmers. Use of tarpaulins also increased downstream in the supply chain.
- Use of superior storage technologies (hermetic bags and silos) had not increased as dramatically as originally hoped, reaching only 10% among beneficiary farmers. That level, however, was twice that reported by control group farmers [24].

Over the project's duration in Tanzania, post-harvest losses were reported as substantially reduced. The beneficiary farmer group reported losses of less than 20%. In contrast, losses in the control farmer group were nearly double that amount [23].

3.2. Linkages to Iringa Hope Cooperative and Farmer Feedback

Established in 2010, the Iringa Hope cooperative [30] is a registered cooperative with headquarters in Iringa, Tanzania. Iringa Hope employs a distinctive cooperative business model comprising thirty local cooperative societies. Each local society is self-governed and is member owned and operated [31,32]. These self-sustaining societies strive to help alleviate poverty among their SHF members and to empower agricultural entrepreneurship.

There are three key organizational elements within the Iringa Hope structure [30]:

- SACCOS are local entities that provide micro loans to SHF members and manage the effective, sustained operation of credit provision and repayment.
- AMCOS are local entities whose purpose is to provide a trusted venue where SHFs can purchase inputs and sell their crops.
- The Micro Finance Institute (MFI) provides services in the Iringa and Njombe regions. It is organized in partnership with Iringa Hope US, the ELCT Iringa Diocese and the University of Iringa. The MFI provides financial services, training and education and access to inputs and markets through the cooperative-level bodies, Iringa Hope Joint SACCOS and Iringa Hope Joint AMCOS.

Data collected within the cooperative's operations indicate that the efforts of Iringa Hope have enabled member families to achieve significant increases in income. Repayment rates are approximately 95% on loans that average USD 357 in size. Organizational overhead is maintained at less than 1% [30].

Iringa Hope and its local coops were active participants within the YieldWise implementation efforts managed by AGRA. Post-harvest education and training efforts were provided to the participating Iringa Hope farmers and support staff within Iringa Hope. Similarly, YieldWise activities provided access to important PHL-reducing technologies and practices that were made available to interested Iringa Hope members. These included access to moisture meters, tarpaulins, hermetic bags, and silos.

Importantly, these key elements of the YieldWise post-harvest initiative were provided within the broader context of Iringa Hope activities focused on improving agronomic practices and strengthening post-harvest management capabilities. In addition to the micro loan program previously described, Iringa Hope provides extensive education and training efforts, as well as on-farm consultation to improve the management of maize production and marketing. These emphasize appropriate agronomic practices related to seed selection, the amount and application of fertilizers and pesticides, and tillage. Further, in more recent years, Iringa Hope has initiated a storage loan program where members can receive loans for cash at harvest time using appropriately stored grain as collateral.

Small-Holder Farmer Response to the Introduction of PH Practices

Macro level impacts, such as those provided above, are important to understanding the reach and depth of an intervention such as YieldWise. However, actual implementation occurs at the very micro level of the SHF. AGRA's YieldWise efforts started in 2016. This project's efforts were conducted in late 2021/early 2022 and included more than 60 interviews. In selecting participants, Iringa Hope staff were asked to ensure that members with a diversity of experiences were recruited. Those would include both active participants and non-participants in the YieldWise effort. Each interview was conducted at the member's farm site or the local cooperative society facility depending upon the interviewee's preferences. SHF respondents were assured of the anonymity of their responses. Each interview was designed to take 45 to 60 min and was conducted by a trained, professional interviewer. An Iringa Hope staff member assisted by making introductions and coordinating logistical issues.

Each interview was divided into four sections. In the first section, informants were asked to recount their backgrounds, education, and prior experience in farming. In the second section, responses were obtained to a series of questions regarding the details of their farms (e.g., size, average yields) and the storage method they used for maize. The third section obtained data on the respondents' experiences in using PICS bags (PHL-reducing technologies and practices introduced through the YieldWise Initiative), focusing on their decisions to adopt PICS bags and the benefits and challenges of using PICS bags. In the last section, informants reported their general experiences in selling maize in the market and their relationships with other organizations and individuals.

The information provided here is derived from 40 interviews randomly selected from the pool of interview data we collected. Specifically, farmers shared their experiences with use of Purdue Improved Crop Storage (PICS) bags, a technology supported by the

YieldWise Initiative to reduce PHL. Conducted in the local language, each interview was transcribed and translated to English. Farmer numbers included in the following tables are internal to the project and are provided to allow the reader to see if a particular farmer is listed in more than one table.

Responses across several important factors are reported in the following tables. The first five tables provide responses that describe the farmer perceived benefits of the YieldWise Initiative and the remaining two tables focus on associated challenges experienced by the participants. Direct quotations, in a few cases slightly edited for length, are reported. To the extent possible, the farmer comments are depicted using the terms and expressions the respondent provided. The responses shown provide the general perspectives of the survey responses even though presentation of the number of specific responses is limited.

Table 1 focuses on the perceived benefits of the storage-enhancing capabilities of the PHL-reducing technologies and practices introduced within the YieldWise project. Overall, 82% of the sample respondents made at least one comment referring to protecting the harvested crop during storage as a benefit.

Table 1. Protecting harvest during storage as a benefit (82% of respondents).

	Illustrative Comments
Farmer 4	*[The reason] why I am using those [PICS] bags on my yields and especially maize because they can preserve maize for 3 years without any loss . . . it reduces [post-harvest loss] so much.*
Farmer 13	*PICS bags have really helped us because if you tie them well, they are not infested even for two years . . . they are not infested at all. They remain very safe even when you want to mill whole maize flour you just mill.*
Farmer 31	*It stays for long without getting spoiled . . . The maize would be in a safe place where it could not be infested by insects. This method of storing maize was better than storing maize in the usual sacks and adding pesticides. The PICS bags are better because we don't add pesticide and it is safer for storage . . . The maize can be stored for a long time . . . we store food well for a long period. I stored six bags and these will cover me for 12 or 8 months. The maize will stay in good condition until then. Insects will not attack the maize.*
Farmer 33	*I was pleased by the idea of storing maize in PICS bags. Maize lasts longer . . . After seeing the benefits of storing maize in PICS bags as opposed to using pesticide which is efficient for only six months and is put in the usual sacks . . . That is one for the major benefits . . . Up to date, I am not worried that losses can be incurred if maize is stored in PICS bags. These bags are very useful.*
Farmer 34	*I was motivated [to use PICS bags] because it was a good thing. I need something to remain in a good condition. That is what motivated me . . . Maize safety till the end. The maize remains in good condition and clean just like they were when we stored the maize. That is why I keep using them.*

The common practice prior to the introduction of hermetic storage bags was to apply pesticides when the maize was stored to control insects during the maize storage period. Table 1 presents several SHF comments indicating health concerns regarding pesticide use as well as potential health issues related to aflatoxin in grain that was not carefully handled before storage. Strong expressions of concern relative to the introduction of pesticides are noted. This is understandable because of the role of maize as a staple food in the SHF household.

These comments are particularly interesting, as they stress that the use of PICS bags can extend beyond a single season. It also is noted that protection in the PICS bag exceeds the length of protection offered by pesticides. All participants are experienced farmers and, therefore, can use that experience to support these comparisons.

The common practice prior to the introduction of hermetic storage bags was to apply pesticides when the maize was stored to control insects during the maize storage period.

Table 2 presents several SHF comments indicating health concerns regarding pesticide use as well as potential health issues related to aflatoxins in grain that were not carefully handled before storage. Strong expressions of concern relative to the introduction of pesticides are noted. This is understandable because of the role of maize as a staple food in the SHF household.

Table 2. Addressing health concerns as a benefit (regarding pesticides, 80%, and aflatoxins, 12.5% of respondents).

	Illustrative Comments
Farmer 1	*(Pesticides) There are [some] good benefits. First, maize is safe without chemicals and pesticides. That is good for the health . . . All pesticides are poisonous. That is what I am avoiding. If it were possible, we could store maize for sale in PICS bags. It is not a good thing to sell poison to others.*
Farmer 36	*(Pesticides) When we were told that sometimes we consume a lot of poison because of adding pesticides to the maize and we then consume the maize. That is what convinced me to start storing maize in PICS bags which do not require us to add pesticides.*
Farmer 37	*(Pesticides) When you store maize in the normal sacks, you are adding poison to food but the food that you get from PICS bags is safe. It has no chemicals or anything. You are doing this knowing that you will sell and there is someone who will be affected by what I am doing.*
Farmer 39	*(Pesticides) The chemicals that we spray on maize affect our health. These chemicals expire after a year and a half and within one year, I consume the maize. I see a problem in terms of health matters. PICS bags are better . . . they are safe for your health . . . I realized it would better for my health because my health is everything. If I buy these bags, my health will be better.*
Farmer 13	*(Aflatoxins) . . . if you dry them down on the ground, there are the aflatoxins that form on the maize. But if you dry them using the canvas they remain safe.*
Farmer 40	*(Aflatoxins) . . . there are benefits [for using PICS bags] because you know when maize is stored while it still has a lot of moisture, the maize forms molds and that changes the maize completely. And the maize loses its goodness. And then also, there is formation of aflatoxins once the maize has moisture. That means it is harmful too for human consumption.*

Aflatoxin contamination is a potential health problem for maize (and other commodity) consumption around the world. Practices to minimize those concerns are routinely employed in the United States and many other countries. Awareness of these issues and of practices to minimize the potential health effects tend not to be known among SHFs in Tanzania and other African nations. One benefit of the YieldWise training was the provision of information regarding the concern and means to combat it. The last two comments in Table 2 suggest that this information has been communicated and absorbed because of the training. Using tarpaulins and ensuring that the grain is dry before storage are important means to minimize aflatoxin development.

Obtaining an improved price for the grain sent to market is, of course, a primary factor of interest to SHFs. Table 3 provides a set of comments that emphasize the potential for enhancing economic well-being through use of more effective PHL-reducing practices. The experiences described in this table indicate that Iringa Hope members who have used those practices have received preferential treatment in their marketplace. These comments indicate that economic benefits extend beyond just reducing the amount of grain that is lost and include monetary recognition for the higher-quality product stored in PICS bags.

Table 3. Improved price control as a benefit (55% of respondents).

	Illustrative Comments
Farmer 2	*. . . our maize is in good condition just like you harvested them so you don't have to negotiate the price.*
Farmer 8	*I sell [maize] at a price that I want . . . because if I have stored my crops and they are good with no doubt the price will be high . . . because if you store [maize] using pesticide, there are other people who don't like it because the pesticide is just chemicals . . . So if you store using PICs bags because that's what I have, you will sell at a price that you want.*
Farmer 9	*. . . you can sell the maize at a very good price because they have not been infested. Another person can sell at a lower price because their maize has been infested so they'd rather sell it just like that. But using PICS bags you can sell at a price that you want and if someone doesn't like the price, I tell them to leave it . . . and it can push you for a longer period . . . So you can sell the maize at a price that you want compared to the one that is mixed with pesticide, a buyer can come and tell you to give them at a price that they want and then they go and sell it at their own price.*
Farmer 29	*The buyers rush for the maize that's in PICS bags . . . You could sell at 60 and I sell at 65. You could sell at 50 and I sell at 60 . . . If the maize prices are low this year, you can store the maize in PICS bags and leave them until next year. That's also a benefit.*

Table 4 addresses additional aspects of the market benefits from use of PHL-reducing technologies and practices. The two factors noted here are market access and ease of processing. SHFs often are challenged when they have grain to sell but no buyer comes to the farm or when there are few buyers at the local market. In those situations, if grain can be sold at all, it is done at a distressed price.

Table 4. Improved market access as a benefit (regarding market availability, 47.5%, and processing ease, 12.5% of respondents).

	Illustrative Comments
Farmer 7	*(Market availability) You get clients quickly when you want to sell . . . . [market] is available because of the good quality of the maize.*
Farmer 13	*(Market availability) Maize that has been stored using PICS bags, you are assured of the market compared to these ones that are being stored anyhow.*
Farmer 17	*(Market availability) I was forced to use pesticides so that I can wait for the price to go up. But after that, that's when they brought PICS bags so we store the maize for sale there . . . the benefit of getting buyers . . . The person who will sell his maize without question is the person whose maize has no pesticides . . . Those ones want maize that has no pesticides so if you have maize that has pesticides you can't sell to them. . . . so one of the benefits is that you get a sure market.*
Farmer 34	*(Market availability) Another benefit is that if you have some maize remaining, you can sell to someone else without a problem . . . At the moment, many people want maize that is free from chemicals. If you have that maize, it is easy for buyers to get it from you . . . One of the benefits is that you have the market. Those who use maize for feeding livestock such as chicken, if they hear that I have 50 sacks that have not been sprayed with pesticides or any chemicals, it is easy for them to come and get it at the price you quote yourself and which will probably will be in the market. They accept it.*
Farmer 3	*(Processing ease) Secondly, even for those who consume dona (whole maize kernels milled into flour including the skin), they don't have to wash the grain. If I spray pesticide, I have to wash the maize to ensure the pesticide is washed away then you dry the maize.*

Table 4. *Cont.*

	Illustrative Comments
Farmer 10	*(Processing ease) . . . if I want to mill maize flour I just take and go to mill because it's clean. compared to the other one you have to wash and then dry them before milling. This one you just take the amount you need put in a basket or pick up and then go to mill.*
Farmer 29	*(Processing ease) The maize stored in the PICS bags is clean and you take it straight to the mill. It is less cumbersome.*
Farmer 30	*(Processing ease) The food stored in the bags is safe and clean compared to adding pesticides and there's dust so you have to wash and all that. The ones from PICS bags, you only have to sort and that's it. After that, if you want you can take them to the millers. There is no dust or dirt in the bag because you sorted the maize prior to putting them in the bag.*

The comments reported here indicate that SHFs have benefitted because their better-quality grain is considered as being more marketable than grain stored with traditional practices. Having a preferred product, in this case because of not using pesticides and less insect damage, can be an important factor, particularly when overall supplies of maize are abundant. The second factor noted is the ease of processing the higher-quality, PICS-stored grain. Apparently, this is an important benefit both when the grain is to be processed for the SHF's home consumption or for sale to processors.

The capability of PICS bags to deliver better performance and also to reduce costs was noted by the SHF respondents, and illustrative comments are included in Table 5. Because of the multiple layers of covering in the PICS bags, farmers noted that rodents had more difficulty smelling grain in the bags. Further, the strength of the multiple layers was reported as reducing the potential for tearing during handling of the bags. A second benefit reported in this table was the reduction in expenditures associated with not having to purchase and apply pesticides. Combined with the potential for using the bags for multiple seasons, reduced expenditures for pesticides each season can be significant.

Table 5. Better security/durability and cost savings as a benefit (17.5% of respondents for each benefit).

	Illustrative Comments
Farmer 5	(Security/durability) *I realized that the [PICS] bags were good. If you put maize, they don't tear so maize doesn't pour out. Even if there are rats, they can't access the maize. The bags don't get torn like the sacks we used to use in the past.*
Farmer 9	(Security/durability) . . . *even the rats can pass the bag and will not know that there is maize inside there. But if you use these other normal bags, when they pass they smell the maize and they start destroying the bag.*
Farmer 21	(Security/durability) *And I've also seen the rats do not disturb us compared to the other bags we were using.*
Farmer 39	(Security/durability) *The material that they've used is very strong and it's doubled. Once you arrange them in your store, they keep well. The sacks that were used in the past could easily catch fire and the maize would pour out. But this bag is strong because the outside bag is strong and inside there's another bag. It's strong. Once you store it, that's okay.*
Farmer 7	(Cost savings) *The benefits are great . . . In the past I used to buy pesticide, I store maize and after a while insects infest it. You buy more pesticide to add to the maize. The expense of building granaries time and again has gone down. The expenses of storing maize have gone down due to PICS bags.*

Table 5. *Cont.*

	Illustrative Comments
Farmer 17	Cost savings) . . . *the second benefit is that you don't buy . . . pesticides every year because the bag itself is safe enough. So once you buy it once it all depends with how you take care of it because it can last for even three years just using the same bag.*
Farmer 38	(Cost savings) *Another benefit is that I don't incur expenses of buying pesticides because at some point you need to add more pesticide so that the pests are kept away . . . There is a difference. For 100 kgs there could be a price difference of 10,000.*

The study's interview process explicitly encouraged the SHF respondents to detail concerns and challenges associated with the PHL-reducing technologies and practices introduced through the YieldWise Initiative. As demonstrated in Table 6, the Tanzanian SHFs who provided responses did stress the high price of bags as a challenge.

Table 6. High price of bags as a challenge (57.5% of respondents).

	Illustrative Comments
Farmer 4	*I have delayed using the [PICS] bags. yes, I have delayed I did not start early. And the reason for that was the price of the bags . . . . they are expensive. So most people cannot get them because of the price.*
Farmer 32	*The only drawback is that the bags are expensive. They cost 4500–5000 shillings and at times even 6000 shillings . . . The drawback is the high price.*
Farmer 37	*The challenge we have is the purchasing of PICS bags. You could be having plenty of maize but PICS bags are expensive. That is the challenge. You want to store all your maize in PICS bags but you do the calculations and realize that the price is high.*
Farmer 40	*Secondly, it is the cost of the bags. Many people find it too high. Because I may have four bags, I can take chemicals worth 4500 Shillings or 3500 and treat four bags. But as for PICS, since for me to get the four bags, it costs me 20,000. That is one of the challenges that the farmers face is that . . . a lot of money. I was doing the math- If I get the PICs bags and I want to sell the maize, how much shall I sell the maize at? One PICs bag contains five or six buckets. When the middlemen come to buy the maize, they want more than seven buckets in those big wholesale shops. That means that I have to sell two of those PICs bags which I will [combine to form one normal bag and then I put a smaller price tag. They see that as a loss in every sense.*

The expenditure to purchase multiple bags is a significant lump sum amount, which typically would be incurred just prior to harvest when cash is normally in short supply. Experience with the multiple season use of bags would mitigate the "sticker shock" factor, but the cash (or credit) still must be available. Because the purchase of tarpaulins and bags is a practice that is new to this community, the cash amount required will receive scrutiny. Further, scale factors that could reduce the costs of providing these tools do not yet exist in the marketplace. All of these elements combine to focus attention on the cash cost of these new tools.

A number of the benefits noted previously accrued to farmers who not only used the technology but understood both how to use the technology effectively and its limitations. These farmers recalled lessons learned in the training as they properly used the technology. In contrast, other farmers did not fully understand or recall how to use the technology. Table 7 identifies lack of training and lack of trust as important concerns and challenges. Interestingly, two dimensions are illustrated in the lack of training challenge. One dimension is that those who "joined the trainings are few" (Farmer 4). Not all SHFs in the village participated in the YieldWise-sponsored activities. This means that many of the local SHFs were not aware of the potential benefits. Those who did attend may well have had their confidence tested when communicating later with those who had not attended.

Table 7. Lack of training and lack of trust as a challenge (57.5% of respondents).

	Illustrative Comments
Farmer 4	*(Lack training) … the ones that joined the trainings are few. The officers that have been training people use government public meetings but still the response from people is low. They forget that they can still use these bags for more than three years, even if they buy them at a cost of 4000 but they can still use the bags for many years. So I know there are a few people that use these bags. … the ones that are being closely trained are few.*
Farmer 9	*(Lack training) … the challenge that I had, because no one had explained to me deeply. That if you use this bag you will not have that problem of mixing pesticide all the time, the bag itself is enough.*
Farmer 34	*(Lack training)The first year I used [PICS bags], I encountered losses. While storing, I leaned the bag on the wall. The moisture penetrated the bag and the maize became black on one side … I was worried. A problem arose and I told myself those people were liars. I bought the bag at a high price and these are the results. They are not trustworthy. I think it also contributed towards not adding more bags. The following year, since we had forwarded our complaints that we stored maize and this had happened, I had proof that I had used the bags and this is how the maize turned out. The subsequent year, I followed their instructions. We were not supposed to lean the bags on the wall or put the bag to touch the ground. I put the bag in a safe place until the last minute. We used the maize until March-April of the following year and the maize was okay. That's when I accepted that it was true.*
Farmer 37	*(Lack training) Our village has many people. I think those who don't use PICS bags don't use them because they lack information. For instance, take me as an example, I used to hear about PICS bags. If you ask me what a PICS bag is like, I can't explain. I did not know the benefits. Later on, after attending the seminar, there are many things that were revealed. I realized that there are great benefits in using these bags.*
Farmer 31	*(Lack trust) When something is new, you don't fully trust it. When you start a business, you wonder whether the results will be good or bad. You expect profit and loss. You can solve some problems and some you cannot. In this regard, we decided to test and see whether [PICS bags] are good.*
Farmer 33	*(Lack trust) … the first time you get something new you wonder whether it is possible. I remember in the beginning, in the bag where I had put the maize, the maize was outside so it got spoiled. That was the first time. The second time round, I concentrated very well and said I have to put the maize properly so that I can see. Later on, I folded it well and then I poured my maize inside. To date there hasn't been any issues … Some things are foreign, we don't even know about them. There wasn't much information but when we obtained sufficient information, we realized these bags were good.*
Farmer 37	*(Lack trust) I tried [the PICS bags] and the challenge was whether it would be the same as I was taught. That's why I'm telling you it reached a point I went to open the bags to see. The challenge was brought on by myself due to lack of faith in whatever I was taught.*

A second dimension is related to the "depth" of the training. It is reported that, on occasion, inappropriate practices (applying pesticides when not needed or exposing the bag to moisture) were performed, reducing the effectiveness of the improved practice. No training session is likely to inform participants perfectly and comprehensively, especially as time passes after the session. However, these comments underscore the need to continually strive to improve training methods and their effectiveness, as well as offer refresher training and reminders.

Similarly, skepticism and lack of trust certainly should be expected when novel methods are introduced. Efforts that can mitigate the challenges that lack of trust may bring deserve priority. However, there will be instances when lack of performance occurs, which may result from SHF "error". These comments underscore the need to be able to respond to those occurrences, often with further training and/or one-on-one support and troubleshooting. While that capability often exists within a pilot program setting, it is important that entities that can provide such service are available after the pilot effort ends.

3.3. Linkages to Iringa Hope Cooperative and an Economic Illustration

In Tanzania, the PHL-reducing technologies and practices introduced within the Yield-Wise Initiative primarily involved farm-level actions: use of moisture meters, tarpaulins, and improved storage devices. However, the economic and family benefits associated with adoption and use of those interventions can be affected both by other on-farm actions and by improved linkages with non-farm actors who supply inputs and who link farm output to downstream markets.

This section of the article provides an economic illustration of the potential benefits from use of PHL-reducing practices, emphasizing the interplay between PHL reduction and other complementary innovations. Comparisons presented here are organized within the context of the following four scenarios:

- The Baseline, where no intervention activities are conducted,
- PHL Reduction Only, where technologies and practices that have been shown to have a strong likelihood of technical success are employed. These include a focus on cleaning and drying grain (including use of moisture meters and tarpaulins) before storage, use of hermetic storage bags and education/training.
- Yield Increases Only, which focuses on Iringa Hope's innovative efforts to increase agronomic productivity. These comprise a package of activities including the use of improved seed, application of appropriate levels of fertilizer, available credit for purchasing inputs, and education/training.
- Post-Harvest Management, where the use of both PHL-reducing and yield-increasing technologies noted in the prior two scenarios are combined with an innovative storage loan program. In that program, farmers can receive loans at harvest equaling 60% of the grain's value. These funds provide cash flow for family and farm activities. When the grain is sold later in the year, the revenue is used to repay the storage loans.

An Excel-based model was employed to compute the economic estimates that will be shown here. Working in concert with Iringa Hope and its members, a driving purpose was to conduct an analysis reflective of the circumstances of SHFs in the Iringa region. Where possible, published data and research article results were reviewed and made available. The intent of this effort was to examine conditions and potentials of Iringa Hope members from their perspective. Therefore, primary data were collected from member farmers and Iringa Hope staff members who worked directly with the farmers. Project staff conducted in-depth interviews with the Iringa Hope participants during the early months of 2022 to obtain the coefficients used within this modeling exercise. Data provided tended to be consistent with similar information reported in published sources. Further questioning was conducted when clarification was needed.

The economic framework employed was that of a partial budgeting approach. This method has a long tradition of providing useful economic information, particularly when detailed accounting records are not available. In this approach, the practices and coefficients of the Baseline scenario are the starting point of the analysis. Estimates for physical factors (such as inputs used, yields, grain needed for household consumption, and losses) and associated costs and revenues are specified. These baseline coefficients become the anchor point for comparisons with the other three scenarios. Within each scenario, estimated coefficients for those factors that change from the baseline are employed. For example, additional costs associated with the use of meters, tarpaulins, and PICS bags are included in the PHL reduction scenario. In that scenario, however, yields are kept at the same level as in the Baseline scenario.

Table 8 provides an overview of these economic results. These results illustrate the differential results when the direct effects of PHL reduction are supplemented by complementary actions addressing key institutional voids.

Table 8. Economic comparison of the four scenarios.

	Baseline	**PHL Reduction Only**	**Yield Increases Only**	**Post-Harvest Management** [1]
Receipts from all sales	93	31	273	353
Total receipts, including storage loan	93	31	273	490
Total production and storage costs	(26)	(30)	(134)	(172)
Total expenditures, including loan repayment	(26)	(30)	(134)	(309)
Net cash flow from production and storage	68	1	139	181
"Potential grain purchases" to meet consumption needs	(147)	0	(147)	0
Net cash flow (including "purchase" of needed grain)	(80)	1	(9)	181
Net benefit (over baseline)	0	81	71	261

[1] This scenario indicates the combined effect of the PHL-reduction and yield-increasing interventions as well as the storage loan program.

Baseline results: The estimated result for each of the four scenarios is shown as a separate column in Table 8. The Baseline scenario depicts conditions prior to both the introduction of agronomic improvement efforts by Iringa Hope and its collaboration with the YieldWise Initiative to better manage post-harvest loss. The Baseline conditions document the SHF's economic challenges when limited to the use of low-productivity agronomic practices, traditional high-loss storage practices, and limited availability of credit.

With those parameters, estimated annual net receipts (USD 93) do exceed direct production and storage costs (USD 26). However, because of the high-loss storage practices and the need for cash flow, all production is sold at harvest when prices are typically depressed. The stipulation that all production be sold likely is an overstatement, as some production probably would be maintained for consumption immediately after harvest. In that regard, this, and other, assumptions used in this analysis should be viewed as boundary conditions. The economic models developed for this analysis could have provided estimates for a situation where a small amount of grain is maintained in the household at harvest. However, the associated assumptions would have added complexity to the comparisons without materially affecting the lessons learned from the analysis. Because the entire crop is sold at harvest, grain must be purchased from local markets for home consumption throughout the year. Typically, those purchase prices will be higher than the farm gate price and, importantly, often increase significantly later in the year when the next year's crop is still unavailable. Table 8 results reflect these trends by providing an estimate of the family's "potential grain purchases" (USD 147). The net effect is that the estimated maize cash receipts fall short of the estimated funds needed to purchase grain for home consumption (USD −80).

Quotation marks are used here and in Table 8 to emphasize that the economic estimate shown underestimates the true human costs of the situation. For a purchase to occur, cash needs to be available. Particularly as the year progresses, cash availability becomes a challenge. The result is the "hunger months" so effectively described by Thurow [33]. Often, that hunger is unequally felt in the family, with the woman suffering to the greatest extent. The purchase estimate and the associated negative cash flows (USD −80) express distress in economic terms, but conditions in the farm household likely are substantially more dire in human terms.

PHL Reduction Only: The second column of data in Table 8 provides estimated results for the scenario where appropriate PHL practices are applied. Those practices are assumed to allow the farm family to store grain in the household in sufficient quantities so that additional grain does not need to be purchased during the year. Grain, in excess of that needed for consumption, is sold at harvest to provide cash for family living and other farm expenses. The estimated sales (USD 31) are lower than in the Baseline because part of the crop is stored for family consumption. Total production and storage costs increase slightly relative to the baseline.

The resulting net cash flow estimate is positive (USD 1) but very small. In a comparative-statistics, economic comparison, the use of appropriate PHL-reducing tools has resulted in an economic gain (USD 81). However, the family's cash position has not been substantially enhanced. Its ability to advance by employing better farming practices and to increase family well-being are restrained. Further, it should be noted that the economic results shown here are depicted in unrealistically clear terms. Among the many signals and challenges that the farm family experiences on an on-going basis, the message that use of better PHL tools delivers benefits may be muted if cash shortages persist.

Yield Increases Only: A challenge illustrated in the previous scenario is that the farm family's economic potential is limited because of the use of low-productivity agronomic practices. The Yield Increases Only scenario relaxes that constraint. However, it is assumed that traditional, high-loss PHL practices continue to be employed.

In actual practice, effective use of improved seed and appropriate levels of inputs have led to markedly higher yields for Iringa Hope's members [33]. The estimated revenues for this scenario (USD 273) illustrate that impact. Production costs also increase (USD 134). Net cash flows from sale at harvest (USD 139) are materially enhanced.

However, the second aspect of this scenario, that ineffective PHL practices remain, has a marked negative impact. As in the Baseline scenario, all grain is sold at harvest. This means that significant funds (USD 147) again need to be expended to purchase grain during the year for household consumption. Again, the benefit comparison indicates that the Yield Increase Only scenario provides an economic improvement. However, the net cash flow is slightly negative (USD −9).

Post-Harvest Management: This scenario combines and expands upon improvements analyzed in the prior two scenarios (effective PHL tools and improved agronomic practices). In the two prior scenarios, farmers were constrained by cash flow limitations to sell all excess grain at harvest. However, in the PHL Management scenario, the small-holder farmers have the opportunity to secure loans equal to 60% of the value of their crop.

The potential impact of this opportunity is demonstrated in the estimates shown in the fourth data column of Table 8. Market receipts (USD 353) are estimated to be higher because grain is sold later in the year when prices typically are elevated. Loan proceeds further inflate the amount of cash available (USD 490). Of course, loans must be repaid. That repayment and interest is included in the total expenditures category (USD 309).

Because of the use of appropriate PHL-reducing tools, grain for home consumption is stored in the household. Therefore, no purchases of grain later in the year are recorded.

The overall positive impact of these integrated innovations is indicated in the estimates of net cash flows and net benefits. Net cash flows (USD 181) are substantially higher than in the alternative scenarios. Similarly, net economic benefits (USD 261) reach their highest level because of the reduced need to purchase grain for home consumption and better market returns.

It is important to note that grain prices after harvest do not always increase in concert with the typical increases employed in this analysis [34]. Education, training, and practices to mitigate the negative economic effects when typical price increases are not achieved do exist. Public support, such as through self-supporting revenue insurance schemes, can effectively reduce risk from post-harvest decline. With or without such schemes, failure to store after harvest means foregoing the positive revenue impacts that normally occur.

4. Conclusions

PHL exists at troublingly high levels, particularly in agricultural systems dominated by small-holder agriculture. This circumstance is somewhat of a paradox, as technologies exist that have been shown to substantially reduce unnecessary PHL. This article explores this persistence, specifically focusing on the discrepancy between pilot project efforts that achieve loss reductions and the tendency for follow-up scaled adoption not to occur. The intent of pilot projects typically is to demonstrate that specific technologies "work" in terms of reducing loss. Achieving scaled adoption does require technologies that work. However, if institutional voids relating to supply chain deficiencies and supporting infrastructure are not also addressed, scaled adoption often does not emerge.

The YieldWise Initiative was an innovative intervention that employed a more systemic approach to the challenge of PHL reduction. Its focus was on PHL among small-holder farmers in Africa. This article explored YieldWise in the specific localized context of maize farmers in the Iringa region of Tanzania. Reflections as to key benefits and challenges of the YieldWise intervention were provided from YieldWise participants who are small-farmer members of the Iringa Hope cooperative in Tanzania. Commonly noted benefits included the ability to securely store grain for extended periods, to achieve high prices for their grain, and to experience potential health benefits associated with not having to use pesticides to preserve grain. Those members also noted that it was difficult to achieve wide participation when some community members did not attend training.

Input from Iringa Hope members and staff was employed to illustrate the value of integrating PHL technologies with complementary interventions. An economic comparison was conducted comparing outcomes from four scenarios: a baseline, PHL reduction only, yield increasing efforts only, and the cumulative effort of the PHL and yield interventions within a more comprehensive post-harvest management effort that included a storage loan scheme. The Baseline scenario depicted results only when low productivity inputs and traditional, low-quality storage were available. Not surprisingly, the results were dire.

Interventions to solely reduce PHL and solely increase yields were indicated to improve economic conditions. However, low productivity in the former case and high PHL losses in the latter were shown to mitigate the intervention effects, resulting in minimal improvement to the farm families' cash position. The combined effect of those interventions within an integrated post-harvest management framework did indicate the potential for improvement in the family's economic well-being. This effect resulted because the farmer could sell their excess grain later in the season when prices typically are high. It should be noted that prices post harvest do not always increase. Schemes to address such risks would be useful. Foregoing the price rises that normally occur, however, means that farmer returns will be limited by the inability to gain from typical price increases.

Further, this research was focused on supply chain activities on either "side" of the crop production activity—availability of input, finance pre- and post-harvest, and storage. However, there are important food waste and PHL issues downstream of the production activity. Efforts to identify where significant downstream waste and loss occurs, the means to reduce loss, and the economic returns from doing so are likely to provide important benefits.

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