AN INITIAL INVESTIGATION OF THE POTENTIAL FOR HERMETIC PURDUE IMPROVED CROP STORAGE (PICS) BAGS TO IMPROVE INCOMES FOR MAIZE PRODUCERS IN SUB-SAHARAN AFRICA

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Dept. of Agricultural Economics

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by
Michael Jones[1], Corinne Alexander[2] and James Lowenberg-DeBoer[3]
Dept. of Agricultural Economics, Purdue University
West Lafayette, Indiana 47907-2056
[1] jones491@purdue.edu
[2] cealexan@purdue.edu
[3] lowenbej@purdue.edu
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Abstract

Pests like the larger grain borer (*P. truncatus*) and the maize weevil (*S. zeamis*) cause significant storage losses for African maize producers. The value of storage protection to a market-oriented farmer is a function of price seasonality, value loss prevention, and their opportunity costs of capital. Evidence suggests that hermetic technologies like Purdue Improved Crop Storage (PICS) bags can be effective against these key maize storage pests, but sustainable technology transfer requires that it be profitable for producers. This analysis references dry weight loss figures from key life science articles and builds on previous value loss research to provide a geographic model for potential storage technology adoption. PICS bag profitability with one and two years of use are compared with the profitability of leading insecticides Sofagrain (deltamethrin (0.5%) and pirimiphos-methyl (1.5%)) and Actellic Super (permethrin (0.3%)+ pirimiphos-methyl (1.6%)). Market regions in Tanzania, Kenya, Malawi, Mozambique, and Ghana are analyzed. Results show superior profitability with PICS technology, and high potential for adoption in Malawi, Mozambique, Tanzania and Ghana.

Keywords: agricultural pests, technology adoption, maize, larger grain borer, hermetic storage, storage economics

JEL Codes: Q16, Q13, O33

Problem Statement

For centuries, maize producers in Sub-Saharan Africa have been plagued by post-harvest losses from insect, rodent, mold and fungi infestations, with small-scale producers representing the most vulnerable populations (FAO, 2004a). Escalating post-harvest maize grain losses in Sub-Saharan Africa have reached the highest levels in recent history with the accidental introduction of the storage pest *Prostephanus truncatus*, or Larger Grain Borer (LGB), into Eastern and Western Africa in the late 1970s and early 1980s (Dick, 1988). The pest has since spread to 18 countries in Western, Eastern, and Southern Africa (Nansen and Meikle, 2002; Cugala et al., 2007).

Where LGB is present, average dry weight storage losses have increased from 5% with indigenous insect complexes to 10%-30% (Dick, 1988). Dry weight losses are known to be much higher with higher yielding hybrid maize varieties (Patenius, 1988). Economic losses are also much higher than dry weight loss figures, as grain value has a strong negative linear relationship with grain damage intensity after exceeding a tolerance threshold of 5% damage (Compton et al., 1998).

In response to these new post-harvest storage threats, national Ministries of Agriculture have promoted shelling of grain and admixing improved comprehensive insecticides like Actellic Super and Sofagrain for grain preservation (Ofosu et al., 1995; Farrel, 1996). Even with appropriate chemicals, storage of six-months may still result in dry weight losses of 7.5% and depress grain market value by 27% (Meikle et al., 2002). Insecticide use in general, however, remains limited (Markham et al., 1996; Stephens and Barrett, 2009) and many farmers resort to inappropriate and dangerous non-grain insecticides which pose great health concerns (Addo, Birkshaw, and Hodges, 2002). Thus, effective low-cost, non-chemical grain protection technologies has the potential for tremendous impact in Africa. Purdue Improved Crop Storage (PICS) triple-layer hermetic storage bags have preserved maize grain with less than 0.5% dry weight losses over a six month storage period in field tests, without the use of chemicals (Hell et al., 2010). This paper reviews the maize storage literature in Sub-Saharan Africa and evaluates the potential performance of PICS bags in comparison with currently promoted storage technologies for regions in Western, Eastern and Southern Africa.

Introduction

In Sub-Saharan Africa, maize is one of the most important grain staples for agricultural income and caloric intake, accounting for nearly 20% of the plant-based food supply (FAOSTAT). Figure 1 illustrates the 2007 food supply and highlights the importance of maize by region. Since 1990, maize cultivated area and production have increased annually by an average of 1.09% and 2.66% respectively, totaling 29,176,475 hectares and 49,695,262 Mt in 2009 (FAOSTAT).

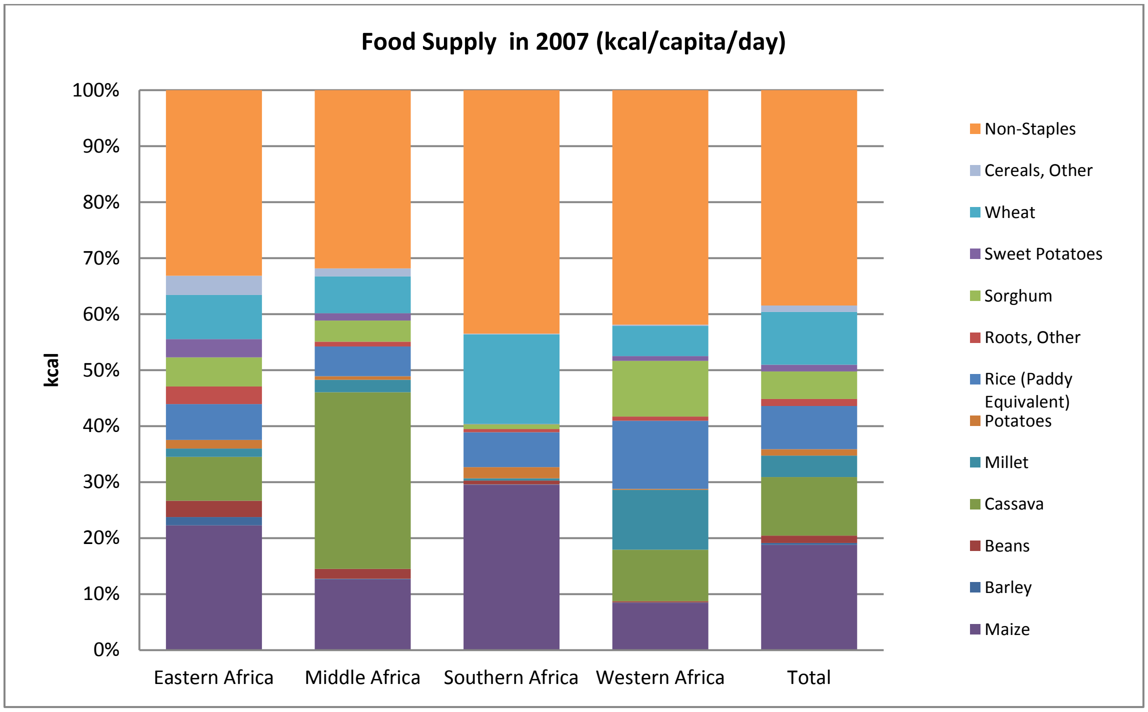

Figure 1: Sub-Saharan African Food Supply in 2007
Source: FAOSTAT

With relatively constant demand, price seasonality is driven by harvest seasons, with the lowest real prices in months directly after the harvest period and highest real prices in the lean season before the following harvest period (Chapoto and Jayne, 2010). Records for 2010 from the Famine Early Warning System (FEWS) illustrate that maize planting and harvesting schedules vary widely across regions, contributing to the regional variation in maize price seasonality. Table 1 presents the West African planting seasons, which are staggered from February through July, and the harvest season, which generally occurs from September to December. The East African regions of Ethiopia, northern Uganda, and northern Kenya have similar seasons, with primary harvests from October through January (Table 2). Harvest seasons in southern Kenya, Tanzania, and southern Uganda can be grouped together, concentrating between May and August. Table 3 shows a concentration of Southern African harvest months between March and June. Several regions in Sub-Saharan Africa have off-season planting and harvest periods, which are possible because of dual rainfall periods or “bi-modal” rainfall. Countries with bi-modal rainfall and two harvests may have less seasonal price variation because there is a more constant supply of grain in the market.

Maize price seasonality and volatility vary among all three regions. Major factors affecting price seasonality include rainfall patterns, geographic proximity of diverse growing seasons, storage costs, domestic transportation infrastructure, exchange rate movements, and discretionary governmental maize policy (Chapoto and Jayne, 2010). These factors affect the level of maize stocks, which will ultimately drive price movement and returns to storage with relatively constant demand (Working, 1949). These same principles drive maize prices in the developed world as well as in the study areas of this analysis (Alexander, Hurt, and Chavez, 2005).

Table 1: Planting and Growing Seasons for 2010

<table>
<tr><th>West Africa</th><th>Jan</th><th>Feb</th><th>Mar</th><th>April</th><th>May</th><th>June</th><th>July</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="2">Burkina Faso</td><td></td><td></td><td colspan="3">PP</td><td></td><td colspan="6">PH</td></tr>
<tr><td colspan="2">OSH</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">OSP</td></tr>
<tr><td>Nigeria (north)</td><td></td><td colspan="3">PP</td><td></td><td></td><td></td><td></td><td colspan="4">PH</td></tr>
<tr><td>Nigeria (south)</td><td></td><td colspan="3">PP</td><td colspan="4">EH</td><td colspan="3">PH</td><td></td></tr>
<tr><td>Niger</td><td colspan="3">OSH</td><td colspan="2">PP</td><td></td><td></td><td></td><td></td><td colspan="3">PH</td></tr>
<tr><td>Mali</td><td></td><td></td><td></td><td></td><td colspan="3">PP</td><td></td><td></td><td colspan="3">PH</td></tr>
</table>

Source: FEWS NET 2010
Abbreviations: PP: Primary Planting, PH: Primary Harvest, OSP: Off-season Planting, OSH-Off-season Harvest, EH: Early Harvest

Table 2: Planting and Growing Seasons for 2010

<table>
<tr><th>East Africa</th><th>Jan</th><th>Feb</th><th>Mar</th><th>April</th><th>May</th><th>June</th><th>July</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="2">Ethiopia</td><td>PH</td><td></td><td colspan="2">PP</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">PH</td></tr>
<tr><td colspan="2">OSP</td><td></td><td></td><td></td><td colspan="2">OSH</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Kenya (Grain Basket)</td><td>PH</td><td colspan="2">OSH</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">PH</td></tr>
<tr><td>Uganda (Unimodal Zone)</td><td>PH</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">PH</td></tr>
<tr><td>Kenya (outside Grain Basket)</td><td></td><td colspan="2">OSH</td><td></td><td></td><td></td><td colspan="2">PH</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tanzania (Bimodal N & NE ridge)</td><td colspan="2">OSH</td><td>PP</td><td></td><td></td><td></td><td>PH</td><td></td><td colspan="2">OSP</td><td></td><td></td></tr>
<tr><td>Tanzania (Unimodal Zone)</td><td></td><td></td><td colspan="2">EH</td><td colspan="3">PH</td><td></td><td></td><td colspan="3">PP</td></tr>
<tr><td>Uganda (Bimodal Zone)</td><td colspan="2">PP</td><td></td><td></td><td></td><td colspan="2">PH</td><td colspan="2">OSP</td><td></td><td colspan="2">OSH</td></tr>
</table>

Source: FEWS NET 2010, GIEWS FAO 2010 (Ethiopia planting);
Abbreviations: PP: Primary Planting, PH: Primary Harvest, OSP: Off-season Planting, OSH-Off-season Harvest, EH: Early Harvest

Table 3: Planting and Growing Seasons for 2010

<table>
<tr><th><u>Southern Africa</u></th><th>Jan</th><th>Feb</th><th>Mar</th><th>April</th><th>May</th><th>June</th><th>July</th><th>Aug</th><th>Sept</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Moz. (North)</td><td>PP</td><td></td><td>EH</td><td colspan="3">PH</td><td></td><td></td><td></td><td></td><td colspan="2">PP</td></tr>
<tr><td rowspan="2">Moz. (S & Central)</td><td></td><td>EH</td><td colspan="3">PH</td><td></td><td></td><td></td><td></td><td colspan="3">PP</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">OSP</td><td></td><td colspan="2">OSH</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Malawi</td><td></td><td colspan="2">EH</td><td colspan="3">PH</td><td></td><td></td><td></td><td colspan="3">PP</td></tr>
<tr><td></td><td></td><td colspan="4">OSP</td><td></td><td></td><td></td><td colspan="2">OSH</td><td></td></tr>
<tr><td>Zambia</td><td></td><td colspan="2">EH</td><td colspan="2">PH</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">PP</td></tr>
</table>

<u>Source:</u> FEWS NET 2010

<u>Abbreviations:</u> PP: Primary Planting, PH: Primary Harvest, OSP: Off-season Planting, OSH-Off-season Harvest, EH: Early Harvest

In a recent cross-country study of select Eastern and Southern African countries, Chapoto and Jayne (2010) found an average of seven months between low- and high-price months. Table 4 presents ratios of high/low month prices for several Eastern and Southern African markets and shows marked differences in maize price fluctuations both among and within countries. When real prices are analyzed, high/low average monthly price ratios may range from 1.44 in Mombasa to 2.65 in Blantyre. Overall, there is a general decrease in high/low month price ratios in the last five of the fourteen-year data set, though markets in Tanzania, Ethiopia and Southern Malawi may be exceptions.

Table 4: Maize seasonal price variability in Eastern and Southern Africa

Average ratio of real high/low month prices							
Country	**Market**	**Season Years ‘94/’95 – ‘07/08**	**Season Years ’03/’04 – ‘07/’08**	**Country**	**Market**	**Season Years ‘94/’95 – ‘07/08**	**Season Years ’03/’04 – ‘07/’08**
Malawi	Karonga	2.23	2.10	**Ethiopia**	Addis Ababa	1.53	1.48
	Lilongwe	2.45	2.13		Jimma	1.83	1.92
	Blantyre	2.65	2.99	**Tanzania**	Arusha	1.84	2.03
Mozambique	Maputo	1.62	1.48		Dar es Salaam	1.82	2.18
	Beira	2.20	1.96		Mbeya	2.03	2.72
	Nampula	2.49	2.09	**Kenya**	Mombasa	1.44	1.31
Zambia	Lusaka	1.77	1.38		Nairobi	1.47	1.43
	Ndola	1.99	1.72		Nakuru	1.64	1.44
	Choma	2.17	1.77	**Uganda**	Kampala	1.91	1.74
South Africa	Randfontein	1.67	1.64		Mbale	1.92	1.79

Source: Chapoto and Jayne (2010)

Maize price volatility and uncertainty increase in countries where governments traditionally take more active roles in market price stabilization, primarily through discretionary trade restrictions and stock releases (Chapoto and Jayne, 2010). Discretionary government intervention may actually destabilize markets as major traders cannot depend on normal patterns of price seasonality. Chapoto and Jayne (2010) found that particularly strong volatility and price uncertainty, quantified as unconditional Coefficient of Variations (CVs), was found in Malawi (45-50%), Zambia (36-45%), and Northern Mozambique (39-41%)[1]. Relatively low price volatility was found in Maputo, Mozambique, South Africa, and all Kenyan markets.

Markets are not isolated, but linked spatially through transportation. Evidence from Ghana suggests that price trends and volatility in the central markets will drive similar price movement in smaller regional and local markets (Badiene and Shively, 1998). Smaller Ghanaian markets also react more quickly to price increases in central markets than price decreases (Abdulai, 2000). Price correlation between markets generally decreases as the distance between markets increases (Roehner, 1995). This correlation is typically lower in inland markets than costal markets, especially where infrastructure is poor (ibid). Evaluations of maize storage economics in Sub-Saharan Africa thus must consider governmental policies affecting the trading environment, whether domestic or international.

Maize Storage in Sub-Saharan Africa

Storage Constraints

Credit and Household Liquidity

Price seasonality between harvest periods allows producers and traders to capture gains from grain storage investments. However, it is not always economically feasible or physically possible for small-holder producers in Sub-Saharan Africa to take full advantage of seasonal price increases. Many producers may sell part or most of their stocks in the period directly after harvest, because of cash constraints, debts, or due to inability to protect against storage losses (Stephens and Barrett, 2009). Early maize sale is quite extensive. For example, Renkow et al. (2004) estimate that almost 83% of Kenyan maize producer sales occur within two months of the harvest period. The timing of maize sales may vary greatly by region, however, as Ghanaian studies indicate a longer average storage period of marketing small-holders of 3-4 months (Motte et al., 1995)[2].

Producers commonly must buy additional grain at much higher prices in the lean season. Among studies of Kenyan small-holder farmers, between 10-19% of producers were found to be both sellers and buyers of maize in the same year (Stephens and Barrett, 2009; Renkow et al., 2004). Further, Stephens and Barrett (2009) found that farmers who sold after harvest and were

[1] The authors noted that volatility in Mozambique was related to strong integration with Malawian markets. Maize price instability in Maputo was particularly low, and the authors generally praised recent Mozambican maize policy.

[2] This author cites average storage periods of around six months before the introduction of new highly damaging insect species.

forced to buy in the lean season had an average loss of 29.3% on their terms of trade. The authors explained the phenomenon of "sell low, buy high" behavior as a market failure from a binding liquidity constraint and low rural credit access. Converting non-cash assets into cash may become necessary, with terms of trade losses representing a "defacto" interest rate over foregone gains from the theoretical storage period.

Many Sub-Saharan African producers face very high costs of capital, if this capital is available at all. Access to formal credit sectors is extremely limited and most low-resource farmers draw from personal funds for agricultural expenses (Gulde et al., 2006). This is an important factor in analyzing grain storage economics. By delaying the sale of grain until prices are higher in the lean season, producers must cover post-harvest expenses by other means. This carries a cost, as these funds are removed from other possible revenue generating activities. The value of alternative uses of a resource is defined as the opportunity cost of an asset or investment (Perloff, 2008). The Opportunity Cost of Capital (OCC) in this context is defined as the foregone returns from alternative uses of capital, had the storage investment not occurred. In the context of formal developed markets, this could be evaluated as the foregone interest from alternative investments for capital in financial markets or institutions (Perloff, 2008). The poorest rural populations are thus unlikely to adopt new production and post-harvest technologies, as the opportunity costs can be too prohibitive (Lowenberg-DeBoer, Abdoulaye, and Kaboré, 1994). Thus, cash-constrained households may be forced to forgo investments in insecticides and other technologies to reduce storage losses and may resort to selling early. In contrast, more cash-secure households store maize for consumption, seed, and future marketing. However, scientists have attributed a recent decrease in storage time to new devastating insect infestations (Addo et al., 2002; Addo, Birkenshaw, and Hodges, 2002).

Moisture, Mold, and Fungus

FAO literature recommends harvesting maize crops 7-8 weeks after flowering, when the kernels contain about 35-40% moisture (Mejía, 1999). Cobs are then generally dried in-field or elsewhere on-farm, and brought to a moisture content under 20%, which continues to decline with storage length. Drying may also be accelerated by hanging the cobs over a smoke source or arranging in "cribs" for maximum natural airflow. General recommendations for seed or long-term on-cob storage (6-9 months) in warm climates is ≤12% moisture content, though this is may be very difficult to attain in climates with high relative humidity (Mejía, 1999).

Certain storage methods are more effective than others at preventing high grain moisture levels, which may lead to mold and fungi contamination, including aflatoxin proliferation (Hell et al., 2000). Clay structures may be overly damp and dark for optimal drying, while improved cribs allow for open air flow and have been shown to reduce moisture contents from 20% to 14% over three months and are associated with decreased aflatoxin contamination in Nigeria and Benin (Hell et al., 2000; FAO, 1992). Field fungi concentrations such as *Fusarium* generally decrease with duration of storage period as moisture content declines (Fandohan et al., 2005). Storage on floors and non-ventilated facilities, however, is not recommended due to ineffective drying and high residual levels of *Fusarium* and contamination of fumonisins (up to 40.3% of kernels infected) (Fandohan et al., 2005). The storage fungus *Aspergillus ruber* is another large concern for maize producers, and is shown to grow rapidly with moisture contents above 15% with normal oxygen levels (Quezada et al., 2006). Table 5 displays that under airtight, or hermetic conditions, *A. ruber* shows significantly lower growth rates under higher moisture contents. This is due to very depressed oxygen levels in hermetic storage, as insects, molds and fungi, and the grain seed itself respire in the confined environment (in order of respiration intensity) (Quezada et al., 2006).

Table 5: Grain Invaded by *A. ruber* in hermetic and non-hermetic storage

Storage Type	**Moisture Content (%)**	**Percent grain (%) invaded by *A. ruber* after storage period**		
		3 days	**9 days**	**15 days**
Non-Hermetic	**14**	**1**	**1**	**2**
	15	**9**	**10**	**10**
	16	**3**	**61**	**83**
	17	**5**	**97**	**94**
Hermetic	**14**	**2**	**1**	**1**
	15	**3**	**1**	**3**
	16	**2**	**1**	**1**
	17	**2**	**2**	**1**

Source: Quezada et al. (2006)

Pests

The most economically destructive maize storage insects in Sub-Saharan Africa are maize weevils (*Sitophilus zeamis*) and the Larger Grain Borer (*Prostephanus truncatus*) (Holst, Meikle, and Markham, 2000). Dry weight losses from *S. zeamis* alone average about 5% by weight after six months of storage (Adams, 1977). This 5% dry weight loss translates into about 22% of total grains displaying damage (Holst, Meikle, and Markham, 2000). Since the arrival of the Larger Grain Borer (LGB) into Togo and Tanzania in the late 1970s and mid-1980s, it has become the single largest threat to post-harvest maize stores in Sub-Saharan Africa, with dry weight losses in six months of storage between 10-30%, with 40-80% of grains damaged (Dick, 1988; Holst, Meikle, and Markham, 2000). Early reports in Togo showed that dry weight losses were four times higher in LGB infested zones, and that improved hybrid varieties were especially susceptible to loss (Pantenius, 1988).

LGB infestations have been reported in Tanzania (1981), Kenya (1983), Burundi (1984), Togo (1984), Benin (1984), Guinea (1987), Ghana (1989), Burkina Faso (1991), Nigeria (1992), Malawi (1992), Rwanda (1993), Niger (1996), Zambia (1996), Uganda (1997), Namibia (1998), South Africa (1999), Mozambique (1999), and Senegal (2007) (Gueye, 2008; Nansen and Meikle, 2002; Cugala et al., 2007).

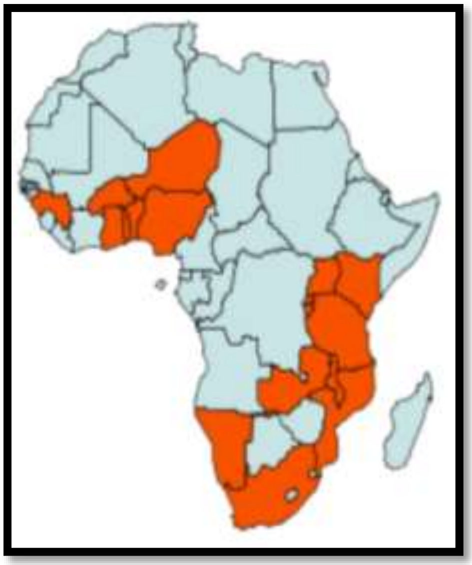

Figure 2: Sub-Saharan African countries with recorded *P. truncatus* infestation
Source: infonet-biovision.org

The arrival of the LGB has led to a large degree of confusion among producers when identifying post-harvest activities that minimize grain damage, as the level of infestation may vary greatly from year to year (Birkenshaw et al., 2002). For example, 24 of 102 sampled stores (23.5%) throughout Benin in the 1997-98 season showed *P. truncatus* infestation and this number increased to 54% in the 1999-2000 season (Meikle et al., 2000; Meikle et al., 2002).

Biological control of *P. truncatus* was attempted in the early 1990s through release of *Teretrius nigrescens*, a natural predator of LGB in Central America. *T. nigrescens* releases have been credited with decreased *P. truncatus* populations in Togo and several other regions (Mutlu, 1994). However, Miekle et al. (2002) view this strategy as a partial solution to the LGB problem and conclude that sole reliance of farmers on *T. nigrescens* populations to prevent LGB attack would be a "risky strategy". In preparation for storage, small-scale farmers have generally increased utilization of pesticides and shell maize crops more frequently, though use of insecticides is still hampered for many producers due to cost constraints (Golob et al., 1999; Addo, Birkenshaw, and Hodges, 2002). The FAO has created a "best practices" guide book for extension officials, *On-farm post-harvest management of food grains*, in which storage recommendations are based on length of grain storage, LGB presence, and hybrid vs. local maize varieties (Golob, 2009). Where the LGB is present, insecticide is recommended with storage of both on-cob and shelled maize. Figure 3 represents a guide for extension recommendations under various decision criteria.

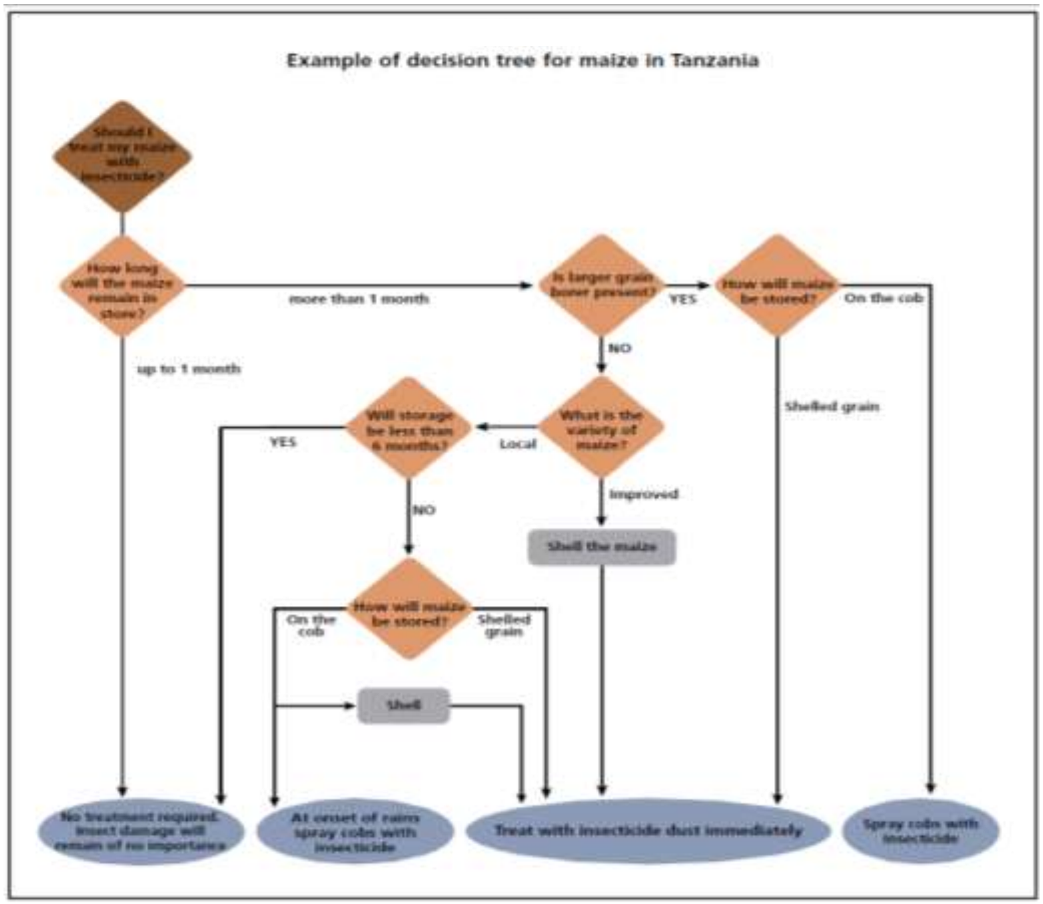

Figure 3: Decision Tree for Extension Guidance on Post-Harvest Storage of Maize
Source: Golob (2009)

This decision tree emphasizes the differentiation of storage techniques between improved (hybrid and OPV) and local varieties of maize, because there is evidence that LGB infestations result in drastically higher losses in improved varieties (Patenius, 1988). Adda (1995) explored dry weight losses between hybrid and traditional maize varieties used in the Volta region of Ghana over a relatively short period of 40 days, in which hybrid varieties withstood damages 100-400% greater than local varieties. As table 6 displays, improved varieties were determined to have less protection from insects due to poorer husk coverage.

Table 6: Storage losses in traditional and improved varieties of maize in Volta Region, Ghana

Variety (local or improved)	Husk type[a]	Grain type	Relative grain hardness	Percent weight loss	Total insect number[b]
Safita-2(i)	Long, medium, loose	White, dent	2.3	12.2	968
Aburotia(i)	Short, weak, loose	White, dent	2.0	11.3	1036
Dorke SR(i)	Short, medium, loose	White, flinty	1.3	9.3	926
Kawanzie(i)	Short, medium, loose	Yellow, flinty	2.3	9.2	812
Obatampa(i)	Short, weak, loose	White, dent		6.8	796
Abeleehi(i)	Short, medium, loose	White, dent	1.8	6.3	720
Penyi(l)	Long, medium, tight	Yellow and white, flinty	1.6	6.0	445
Abutia(l)	Long, medium, tight	White, flinty	1.0	3.0	378
Leklebi(l)	Long, medium, tight	White, flinty	1.2	2.3	434
Dzolokpuita(l)	Long, strong, tight	White, dent	1.4	1.5	255

Graphic Source: Adapted from Golob (2004)
Data Source: Addo (1995)
Notes (quoting Golob (2004)):
(a): short husk = extension less than 2 cm beyond end of cob; long husk = extension more than 2 cm beyond end of cob; strong husk = thickness of all husk leaves combined greater than 0.7 mm; medium husk = thickness between 0.5 and 0.7 mm; weak husk = thickness less than 0.5 mm; tight husk = husk firmly around cob, no punctures or gaps, extended leaves tightly rolled together; losses husk = husk loosely on cob, or extension loosely rolled, or firm husk with punctures, gaps.
(b): Includes larvae, pupae and adults

When calculating losses associated with LGB damage, it is also important to consider the manner in which the grain is being utilized. While maize seed stocks will remain in storage until the next planting period, grain stored for household consumption will be gradually removed for use. "Spot" loss figures for household stocks are thus often overestimated, and consumption patterns will leave only a small amount of grain in storage during the later months of increased infestation and damage. In Tanzania, this figure amounted to only 2% dry weight losses with insecticide use for household consumption patterns over 7-9 months (Golob, 1988). Dry weight losses in Togo, however, have been recorded at 6% of dry weight with household consumption over eight months (Albert, 1992).

Germination

Many producers of OPV and local maize varieties must consider the effect of storage technologies on seed germination rates. Moisture rates in stored seed greatly impact viability (Weinberg et al., 2008). Seed with high rates of fungal infection or insect damage have very low germination rates, which can be as low as 28% of original potential (Quezada et al., 2006). Seed viability is shown to sharply decrease after 35 days of moisture contents above 16% in hermetic storage, discouraging this storage method if lower moisture levels cannot be attained (Weinberg et al., 2008).

Table 7: Moisture content affecting maize seed viability in hermetic storage

Time (days)	Moisture (%)									
	14		16		18		20		22	
	% G	DWL	% G	DWL	% G	DWL	% G	DWL	% G	DWL
0	84.3	-	82.8	-	76.0	-	75.0	-	28.6	-
15	79.9	0.02	78.1	0.03	68.3	0.11	27.7	0.28	10.3	0.51
35	81.7	0.01	79.7	0.05	30.2	0.22	0.0	0.44	0.0	0.59
55	72.3	0.02	21.0	0.15	0.0	0.41	0.0	0.59	0.0	0.74
75	58.3	0.02	21.0	0.15	0.0	0.41	0.0	0.59	0.0	0.74

Source: Adapted from Weinberg et al. (2008)
Abbreviations: G- % Germination, DWL- % Dry Weight Loss

Current Maize Storage Practices

West African Storage Structures

Major storage techniques utilized by small-holder producers in Western Africa vary greatly, but include on-field, open storage, jute bags, polyethylene or polypropylene bags, raised platforms, conical structures with thatched roofs as shown in Figure 4, clay structures, and giant woven baskets (FAO, 2004a; Motte et al., 1995; Addo, Birkenshaw, and Hodges, 2002). Farmers may also store bags in their personal rooms, on cobs above fireplaces, or simply heaped on floors (Ofosu et al., 1995; Hell et al., 2000). These are generally considered “traditional” storage methods, while improved covered structures or “cribs” may be termed “semi-modern”, and formal silos and warehouses termed “modern” storage systems (Sekumade and Oluwatayo, 2009; Adentunji, 2009). Though shelling of grain and insecticide application is officially promoted by many Ministries of Agriculture, storage of maize on cobs (husked and de-husked) is almost universal. If maize is moved during the storage season, however, it is very commonly threshed and bagged (Addo, Birkenshaw, and Hodges, 2002). Specific storage practices vary widely according to climate zone, cultural traditions, and production scale or socioeconomic condition of farmers.

Figure 4: Raised platform (known as an “Ewe” in Ghana, “Awa” in Togo, and “Ava” in Benin) and conical maize storage facilities in the Ghanaian Volta Region and Togo (note on-husk storage)
Source: Addo, Birkinshaw, and Hodges (2002)

Eastern and Southern African Maize Storage Structures

Producers in East and Southern Africa store in small bags with cow dung ash, wood and wire cribs, pits, metal bins, wooden open-air or roofed cribs, raised platforms, and roofed iron drums enclosed with mud, or may hang cobs over a fireplace, (Wambugu, 2009; Farell et al., 1996; Kankolongo, Hell, and Nawa, 2008). In Zambia, many farmers prefer to store maize in a temporary outside structure after harvest until fully dry, then shell and transfer grain to polypropylene bags inside the house before sale, consumption, or planting (Kankolongo, Hell, and Nawa, 2008). Figure 5 displays these various common storage strategies in Eastern and Southern Africa. Insecticide, when used, is applied directly on husked stores as well as admixing with shelled grain in sacks (Dales and Golob, 1997).

Figure 5: Traditional Storage Techniques in Zambia
A: Open-air cribs with wooden pole supports and woven with twigs or bamboo from surrounding forests; B: sacks of shelled maize stored in the home; C: iron drum closed with mud with a fixed roof; D: wooden roofed cribs woven with twigs, bamboo, or thatch grass; E: raised platform on four posts (~2m high) made from tree poles, shrubs, and thatch grass; F: Food Reserve Agency depot where farmers bring grain for sale
Source: Kankolongo, Hell and Nawa (2009)

Strategies for Mitigating Insect Grain Damage

The most prevalent extension recommendations surround shelling grain and admixing insecticide in storage bags. Shelling grain for bag storage has also been officially promoted by national ministries of agriculture (Ofosu et al., 1995;Farrel, 1996), as *P. truncatus* has difficulty boring into grains without the brace provided by the cob (Bell and Watters, 1982). The formula for Actellic Super (permethrin (0.3%) + pirimiphos-methyl(1.6%)) was developed in Tanzania and continues to be the most widely promoted of dust or emulsified concentrates. In Acetellic Super, the permethrin (a pyrethroid compound) effectively kills *P. trucatus* and the pirimiphos-methyl (an organophosphate) controls *S. Zeamis* and other minor pest populations when applied at a rate of 100g per 90kg of maize (Dales and Golob, 1997). Also recommended for control of *P. truncatus* is Sofagrain (deltamethrin (0.5%) and pirimiphos-methyl (1.5%)) (Markham et al., 1996), which is generally mixed at the ratio of one 50g packet[3] per 100kg of maize ears (with husk) (Meikle et al., 2002). Use of other insecticides varies widely among Sub-Saharan African farmers, with common commercial brands including Actellic (pirimiphos-methyl), Sumicombi (fenvalerate and fenitrothion), Percal M (permethrin and malathion), fumigants (i.e. Phostoxin), as well as environmentally detrimental chemicals such as DDT or insecticides generally intended for cotton or cocoa pests (Hell et al., 2000; Addo, Birkenshaw, and Hodges, 2002).

[3] In 1999, one 50g packet of Sofagrain cost 0.54 USD in Cotonou, Benin (Meikle et al. 2002)

Some academic attention has focused on the use of traditional plants and botanicals as maize storage. In the Volta region of Ghana, farmers are known to unsuccessfully attempt to fight *P. truncatus* infestations with neem (*Azadirachta indica*) leaves between layers of stacked maize, as well as liquid solutions made of the bark, seed, or leaves of the plant (Motte, Feakpi, and Awuku 1995). However, this strategy was found by local farmers to be "effective" against *S. zeamis* infestations, though quantitative analysis was not performed.

Cost-Effectiveness of Pest-Control Techniques

Preliminary research in Ghana demonstrates that the cost-effectiveness of pest-control strategies depends on storage period length, infestation level of the most damaging insects- notably *P. truncatus*- and the cost of the storage technology (Ofosu et al. 1995). As the storage period increases in a region with high average losses, the value of the storage technology is measured in product quality maintenance and price increases throughout the period. In zones of high *P. truncatus* infestation in 1995, long-term storage of about six months was not cost-effective using the Ghanaian Ministry of Agriculture's recommended strategy (use of Actellic Super on de-husked kernels). This strategy was cost-effective in short term (~ 3 months) storage in heavily-infested zones, but not in zones with minimal *P. truncatus* infestation (Ofosu et al. 1995). However, the Ofosu et al. analysis was conducted with nominal figures, did not compare returns after storage to returns with immediate sale, and does not differentiate absolute "dry weight loss" caused by insects from voluntary "losses" due to human discarding of damaged grain at the end of the storage period. For these reasons, making direct numerical comparisons of this work to others becomes vastly difficult.

Meikle et al. (2002) conducted more comprehensive field work in central and southern Benin testing the profitability of on-husk maize storage with Sofagrain insecticide use. The authors measured of dry weight loss and estimated the percentage of grains damaged using predictive equations developed by Holst, Meikle, and Markham (2000). They then predicted market value of grain with respective grain damage levels through discount equations derived by Compton et al. (1998) for "mid-season" sales.

Returns for the storage period were calculated using the following equation:

Profit =
[(Maize Store (kg)) x (Market Price at (t) Months after Harvest) x (1 - (% Dry Weight Losses at Month (t))/100) x (1 – 0.85(% Damaged Kernels at Month (t)))] -
[(Maize Store (kg)) x (Market Price at Harvest) x (1 – (% Dry Weight Losses at Base Period)/100) x (1 – (% Damaged Kernels at Base Period)/100)]

In a six-month testing period, Sofagrain was only able to provide positive average returns to storage where *P. truncatus* was absent (Table 8). The authors did not indicate whether the market prices were adjusted for inflation, The authors only considered pesticide costs in the cost of storage, ignoring the opportunity cost.

Table 8: Returns on traditional maize stores in central and southern Benin after six months of storage

	N	Percent Grains Damaged (mean ± SE)	Relative Market Value	Profit, USD (per 600kg store) (mean ± SE)	Profit, USD (per 100kg store) (mean ± SE)
All Stores					
Uninfested and untreated	4	16.8 ± 10.5	0.86	11.95 ± 7.63	1.99 ± 1.27
Uninfested and treated	8	15.5 ± 4.3	0.87	11.00 ± 3.50	1.83 ± 0.58
Infested and untreated	9	50.9 ± 8.6	0.57	-20.14 ± 7.84	-3.36 ± 1.31
Infested and treated	5	31.4 ± 10.1	0.73	-5.59 ± 8.11	-0.93 ± 1.35
Southern Benin Stores					
Untreated	8	50.0 ± 8.2	0.58	-15.90 ± 7.45	-2.65 ± 1.24
Treated	8	32.9 ± 6.4	0.72	-2.88 ± 6.50	-0.48 ± 1.08
Central Benin Stores					
Untreated	5	25.0 ± 14.5	0.79	-1.26 ± 14.50	-0.21 ± 2.42
Treated	5	3.5 ± 2.2	0.97	16.62 ± 2.26	2.77 ± 0.38

Source: Meikle et al. (2002); Scaling to profit per 100kg added by author to facilitate comparison

Purdue Improved Crop Storage (PICS) bags

The triple-layer hermetic PICS bags were developed under the Bean/Cowpea CRSP project in the late 1980s with funding from USAID (Murdock et al., 2003). The hermetic technology works by creating an airtight seal in which oxygen levels are dramatically decreased in a relatively short time through insect, fungal, and seed respiration (Quezada et al. 2006). The high density polyethylene (HDPE) bags, with ultra-thick walls of 80 microns, are produced in 50kg and 100kg capacity sizes and cost between $2 and $4, depending on the region. This technology was originally created for West and Central African cowpea farmers under the name “Purdue Improved Cowpea Storage” (PICS) bags and served as protection against extremely destructive cowpea seed beetles, which prevented long-term storage to capture price increases later in the marketing season. Moussa (2006) conducted an impact assessment of the Bean/Cowpea CRSP project and estimated that, due to the introduction of new hermetic storage technology, over 500,000 tons of cowpea have been conserved which would have been destroyed by storage pests, resulting in $100 million USD in *annual* additional income for producers in West and Central Africa.

With the success of the PICS bags with cowpeas, producers and researchers alike have begun to experiment with its use for storing various other commodities. To date, PICS bags have shown to provide a significant reduction in losses in cassava chip storage compared to conventional polypropylene bags over a two-month period (Edoh Ognakossan et al. 2010). This research is still in progress at the time of this analysis and will yield more long-term results soon. As table 9 illustrates, Hell et al. (2010) also demonstrated that PICS bags can keep dry weight losses in maize below an average 0.5% dry after a six month period with natural and artificial *P. truncatus* infestation. While Hell et al. results are promising and merit an economic investigation for potential profitability analysis, PICS effectiveness with *P. truncatus* is still under further investigation at the time of this work.

Table 9: Maize dry weight losses when stored in PICS bags and standard polypropylene bags

Treatments	Dry Weight Losses (%)	
	3 Months after Storage	6 Months after Storage
PICS Bag	0.28 ± 0.01	0.31 ± 0.01
Traditional (untreated) Polypropylene Bag	9.56 ±.34	17.95 ± 0.51

Source: Hell et al. (2010)

<u>Key Literature Review Conclusions</u>

The importance of maize in the African sub-continent underscores the need for continued innovation in production and post-harvest technology to augment the incomes and food security of small-scale producers.

A review of the literature on maize storage in Sub-Saharan Africa demonstrates that *the greatest demands for low-cost and effective maize storage technologies* will arise in regions where:

1) *P. truncatus* infestation is very high
2) Widespread adoption of hybrid high-yielding maize varieties, which are highly susceptible to insect attack
3) Maize production is meant for market and not solely household consumption
4) Optimal storage periods are generally six months or greater,
5) Discretionary government intervention in maize markets is low, allowing prices to follow normal seasonal patterns with lowest prices directly after the harvest season and highest prices directly before the subsequent harvest season
6) Liquidity constraints and opportunity costs are not prohibitively high
7) If storing maize seed, producers can maintain adequately low moisture content

The widespread adoption of new post-harvest technologies will only be successful when it is profitable. Previous quantitative evaluations of the profitability of maize-post harvest practices have largely ignored the opportunity costs of capital of small producers. This analysis will evaluate the profitability of triple-layer hermetic storage bags for small-scale maize producers in Sub-Saharan Africa, with particular emphasis on the opportunity costs of capital.

As maize is the most important grain crop in Sub-Saharan Africa, especially in Eastern and Southern Africa (FAOSTAT), considerable interest exists to determine the economic feasibility of PICS bags for maize storage throughout the African subcontinent. The goal of this analysis is to evaluate the economic potential for PICS bags for the storage of long-term market-destined maize grain for targeted market regions in Ghana, Tanzania, Kenya, Malawi, and Mozambique.

Data

Monthly real maize prices, based on 2007 prices, from Eastern and Southern African countries from the 1993/94 season to the 2007/08 season are provided in detail by Chapoto and Jayne (2010). Monthly retail prices are provided for Malawi and Mozambique and monthly wholesale prices are provided for Tanzania and Kenya. To focus on the most recent five-year sequence, this analysis utilizes wholesale or retail prices from the 2003/2004 to 2007/2008 seasons. Farm-gate prices in East and Southern African countries are derived under the assumption that farm-gate prices represent 75% of wholesale prices (Kirimi et al., 2010) and 60% of retail prices (Jayne et al., 2010). These margins are assumed to only be relevant in East and Southern Africa, as the studies were performed in this region. Marketing margins are assumed to remain constant throughout the year.

Recent numerical price data could not be retrieved in Ghana on a monthly basis. To estimate monthly price trends, charts of monthly nominal five-year wholesale price averages were utilized from the most recent World Food Program (WFP) and Famine Early Warning System (FEWS) price bulletins (2005-2009). The average low and high price months of the year seem to match other qualitative literature on the general peak of the lean season (June) and the general major harvest month (October) (WFP 2010; WFP 2009). To extract numerical data, the graphics were first copied from the price bulletins into Microsoft Word, then cropped, enlarged, and super-imposed on a respective table which was spaced evenly to replicate major and minor gridlines. Thus, prices could be estimated from the charts with reasonable, yet imperfect accuracy (estimated range of error about 1-2%). Farm-gate prices in Ghana are assumed to represent 66.6% of wholesale prices (Brooks, Croppenstedt, and Aggrey-Fynn, 2007). Marketing margins are assumed to remain constant throughout the year.

Costs of insecticides and polypropylene bags are based on recent field experience in Ghana. The cost of standard polypropylene bags is straight-line depreciated for two years use. As price data for insecticides were not available for each country, costs are assumed to be equal across the continent. The most comprehensive current insecticides, protecting against both *P. truncatus* and native insect complexes, are Sofagrain (deltamethrin (0.5%) and pirimiphos-methyl (1.5%)) and Actellic Super (permethrin (0.3%) and pirimiphos-methyl(1.6%)). Since the deltamethrin and permethrin compounds are the most commonly promoted by ministries of agriculture across Africa, these are used for economic comparison with PICS bags.

Costs of triple-layer hermetic PICS bags in West Africa are based on current prices in Ghana. PICS bag prices for Eastern and Southern African countries are based on U.S. dollar-denominated estimates based on current production costs in West Africa and marketing costs estimated for each country's level of transportation infrastructure.

Thus, prices of PICS bags in this analysis are:

Ghana: based on 2.5 Ghanaian cedi on 01/01/2010 (equivalent to 1.768 USD).
Kenya, Tanzania, and Malawi: local equivalent of 2.50 U.S. dollars on 01/01/10.
Mozambique: local equivalent of 3.00 U.S. dollars on 01/01/10.

PICS storage bag prices were converted into local currency from US dollar-equivalent prices based on the exchange rate at 01/01/10. For Eastern and Southern African countries, 2010 PICS bag prices were then deflated to 2007 prices utilizing CPI figures from the International Monetary Fund (IMF 2010). This was performed to match the baseline year in price data from Chapoto and Jayne (2009) for Eastern and Southern African counties. For Ghana, prices were assumed at the 01/01/10 Ghanaian cedi exchange rate and not deflated, since the only available data were represented by aggregated years.

Methodology

Insect infestation results in both dry weight losses and price discounts for degraded product quality in maize (Compton et al., 1998). Much life science literature presents "losses" in maize storage as only quantity of "dry weight loss" (Cugala et al., 2007; Farrel et al., 1996). Economic literature on the subject, however, indicates that there are price discounts which can be derived from the percentage of damaged maize kernels (Compton et al., 1998; Meikle et al., 2002). The transformations below were made to derive true economic losses from the figures presented in life science literature.

The conversion of "dry weight loss" data to "percentage of kernels damaged" is based on the predictive equation constructed by Holst, Meikle, and Markham (2000) from multi-year field study data in West Africa.

The equation utilized is:
(%D)= - (EXP(-EXP(-3.001+1.005*(LN(%DWL))))-1)*100

Where (%D) is the percentage of damaged maize kernels, (%DWL) is the percentage of dry weight loss, (EXP) is exponential, and (LN) is the natural logarithm. [4]

Value losses from damaged kernels followed Meikle et al., (2002) in utilizing the methodology developed by Compton et al. (1998), which was derived from focus groups of maize traders in northern Ghana. While the study by Meikle et al. (2002) utilized the "mid-season" equation to assess price discounts, this study incorporates the "normal year lean season" figure for more conservative estimations. Compton et al. (1998) found a tolerance threshold of 5-6% damage before discounts were applied, and insect damage was discovered to account for the large majority of devaluation. Predictive value loss equations were reported by the focus groups during plentiful, moderate, scarce, and very scarce maize availability. Tolerance for grain damage was reported to increase with periods of increased grain scarcity. This study assumes maize discounting patterns across Sub-Saharan Africa follow this trend.

[4] See equation [5] in Holst, Meikle, and Markham (2000) with slope and intercept parameters from Table [2] (Regressions I and II pooled)

Compton et al. (1998) recommends the following predictive equations for use in cost-benefit analysis:

- Post-Harvest Season (%V) = 100 – (%D)
- Mid-Season (%V) = 100 – 0.85*(%D)
- Normal Year Lean Season: (%V) = 100 – 0.75*(%D)
- Poor Year Lean Season: (%V) = 100 – 0.65*(%D)

Where (%V) is the percentage of grain value retained and (%D) is the percentage of damaged maize kernels.

Calculating Returns on Storage

The returns to storage were calculated for the following three delivery times: 6 months after harvest, 8 months after harvest, and at the month with the maximum price in the maize marketing season. Harvest periods were determined from baselines in Chapoto and Jayne (2010) and verified by FEWS planting and harvesting timeline data. Returns on storage and technology investment for Eastern and Southern African counties were calculated on a yearly basis under varying opportunity costs. Yearly returns were then averaged over five years to provide a longer-term trend. Storage losses for each technology were assessed using data in LGB-infested zones, as these would be the zones of highest insect losses and thus greatest need of improved storage technology.

All storage returns are benchmarked against the small producers' return from selling directly after harvest. Then the returns to storage are calculated for several storage technologies including no technology, insecticides, and PICS bags. The effectiveness of each of these storage technologies in controlling for losses associated with LGB infestation. Losses without the use of storage technology were calculated with the best estimation from the literature for expected losses for each storage period. For sensitivity analysis, returns to storage are also calculated for 5% above and below this expected loss estimate.

Thus,

$$Total\ Revenue - Marketing\ Costs - Storage\ Costs = Net\ Income \quad [1]$$

$$Net\ Income - Opportunity\ Cost\ of\ Capital - Net\ Income\ if\ Selling\ at\ Harvest = Net\ Gain\ on\ Storage \quad [2]$$

$$Return\ on\ Storage = \frac{Net\ Gain\ on\ Storage}{(Net\ Income\ if\ Selling\ at\ Harvest + Storage\ Costs)} \quad [3]$$

This analysis also considers the ability of PICS bags to be used for a second season. In this scenario, grain was assumed to be marketed in a traditional woven bag the first year and sold in the PICS bag itself the second year. The cost of the PICS bag was straight-line depreciated over two years for this analysis and assumed to have no salvage value[5]. Returns are calculated for each year and then averaged.

As full monthly loss data for a twelve month period does not exist for each technology in each African region, this analysis utilizes sources providing the longest regional complete series. Sources indicate that deltamethrin, the active ingredient in Sofagrain against *P. truncatus*, has consistently proven more effective than permethrin, the ingredient in Actellic Super (von Berg & Biliwa 1990; Golob & Hanks 1990). Actellic Super is also known to break down quite rapidly after several months, leading to a spike of losses in long-term storage with only single dosages (Biliwa & Richter 1990). While loss estimations may vary with weather patterns and LGB intensity, the analysis assumes these general rankings in the effectiveness of insecticides. Long-term losses (9-11 months) for Actellic Super were documented by Biliwa et al. (1990) in West Africa, but the 16.6% dry weight loss figure is utilized in East African countries as well since it follows the documented trend after the chosen East African study ended. Tables 10 and 11 display the percent dry weight losses that are utilized in the analysis.

Table 10: Eastern and Southern African Dry Weight Losses (all areas assumed with LGB infestation)

Storage Period Length	No Storage Technology (%)			Sofagrain	Actellic Super	PICS Bags
	High Losses	Expected Losses	Low Losses			
≤ 2 mo.[6]	0.28	0.28	0.28	0.28	0.28	0.28
3-4 mo.	15	10	5	2.5	3.75	0.28
5-6 mo.	20	15	10	5.5	8.0	0.31
7-8 mo.	20	15	10	5.5	8.0	0.31
9-11 mo.	25	20	15	7.7	16.6	0.31
Source(s)	Conservative ranges from Golob and Hanks (1990), Dick (1988), and Biliwa et al. (1990)			Biliwa & Richter (1990)	Kimenju & DeGroote (2010); Biliwa et al. (1990)	Hell et al. (2010)

Table 11: Western African Dry Weight Losses (Ghana) (all areas assumed with LGB infestation)

Storage Period Length	No Storage Technology (%)			Sofagrain	Actellic Super	PICS Bags
	High Losses	Expected Losses	Low Losses			
≤ 2 mo.[7]	0.28	0.28	0.28	0.28	0.28	0.28
3-4 mo.	15	10	5	2.0	3.75	0.28
5-6 mo.	20	15	10	3.5	5.6	0.31
7-8 mo.	20	15	10	3.75	5.6	0.31
Source(s)	Conservative ranges based on Golob and Hanks (1990), Dick (1988), and Adda et al. (2002)			Adda et al. (2002); Meikle et al. (2002)	Hodges (undated); Kimenju & DeGroote (2010);	Hell et al. (2010)

[5] This is a conservative assumption, as PICS bags salvage value is currently under investigation at Bayero University in Kano, Nigeria

[6] All loss estimates under two months are conservatively taken from Hell et al. (2010), which was measured for PICS bags for 3 months. Losses are shown to be very minimal in graphs from other studies, but numerical figures were not yet found.

[7] All loss estimates under two months are conservatively taken from Hell et al. (2010), which was measured for PICS bags for 3 months. Losses are shown to be near very minimal in graphs from other studies, but numerical figures were not yet found.

Results

Eastern and Southern Africa

Returns on investment were calculated for reported LGB infested zones in the south-western Tanzanian market of Mbeya [unimodal zone], the south-western Kenyan market of Nakuru, the central Mozambican market region of Beira, and the southern Malawian market of Blantyre. These locations represent diverse climatic and demographic regions of the zone and can provide a more comprehensive view of the potential profitability of PICS storage bags in Eastern and Southern Africa.

Mbeya, Tanzania

Table 12 displays the real wholesale data from the 2003/04 to 2007/08 marketing seasons. Wholesale prices generally peaked 9-10 months after the harvest period. Notable, however, is a downward trend of real prices from March 2006 to June 2007, making the most profitable month of sale in the 2006/07 season directly after harvest.

Table 12: Mbeya, Tanzania real wholesale prices for the 2007/08 marketing season (1,000 TZS/Mt).

Season	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
2003/04	135	134	151	158	152	165	169	197	209	232	256	208
2004/05	165	112	137	145	142	158	160	144	264	380	131	146
2005/06	113	160	158	150	153	183	189	250	288	345	359	313
2006/07	296	224	169	201	187	187	182	168	159	123	116	118
2007/08	107	107	127	157	170	154	195	204	261	279	277	252

Source: Chapoto and Jayne (2010)

Farm-gate prices were assumed to conservatively represent 75% of wholesale prices (Kirimi et al., 2010). Table 13 displays the resulting derivation of farm-gate prices for farmers, calculated as 75% of the wholesale prices listed in Table 12.

Table 13: Derived Mbeya, Tanzania real farm-gate prices for the 2007/08 marketing season (1,000 TZS /Mt).

Season	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
03/04	101.25	100.5	113.25	118.50	114.00	123.75	126.75	147.75	156.75	174.00	192.00	156.00
04/05	123.75	84.00	102.75	108.75	106.50	118.50	120.00	108.00	198.00	285.00	98.25	109.50
05/06	84.75	120.00	118.50	112.50	114.75	137.25	141.75	187.50	216.00	258.75	269.25	234.75
06/07	222.00	168.00	126.75	150.75	140.25	140.25	136.50	126.00	119.25	92.25	87.00	88.50
07/08	80.25	80.25	95.25	117.75	127.50	115.50	146.25	153.00	195.75	209.25	207.75	189.00

Source: Adapted from Chapoto and Jayne (2010) with marketing margin from Kirimi et al. (2010)

In Tables 14 and 15, sample yearly return calculations from the 2007/08 marketing season will serve as an example of the logical process to arrive at all yearly return figures in East and Southern Africa. Returns to storage in Tables 14 and 15 are based on maize harvests in May and sale at the month of the highest price.

Table 14: Derivation of Estimated Real Crop Incomes from Various Storage Technologies

	Sell Maize at Harvest	Storage of Maize with Traditional Methods					Storage of Maize with Hermetic PICS Bags
		No Insecticide			Sofagrain (50g/100kg)	Actellic Super[8] (100g/100kg)	Lasting One Season
Selling Period	May	February					
Revenue							
Sample Prod. (kg)	100	100	100	100	100	100	100
DWL (%)	-	20.00	15.00	10.00	5.50	8.00	0.31
Maize Marketed (kg)	100	80	85	90	94.5	92.0	99.69
Kernels Damaged (%)	-	63.57	53.06	39.54	24.11	33.11	1.52
Selling Price (TZS /kg)	80.25	109.49	125.98	147.20	171.41	157.30	209.25
Total Revenue (TZS)	8,025.00	8,758.87	10,708.65	13,248.20	16,198.34	14,471.11	20,860.13
Costs							
Polypropylene Storage Bag Costs[9] **(TZS)**	373.18	373.18	373.18	373.18	373.18	373.18	
Insecticide Costs (TZS /100kg treated)					746.35	746.35	
Storage Bag Costs (TZS)							2110.63
Total Storage Costs (TZS)	373.18	373.18	373.18	373.18	1,119.53	1,119.53	2,110.63
Adjusted Real Crop Income (TZS)	7,651.82	8,385.70	10,335.47	12,501.85	15,078.81	13,351.58	18,749.50

[8] Recommended dosage of Actellic Super is 100g/90kg in Tanzania, based on Dales and Golob (1997), but assumed 100g/100kg for comparative ease

[9] This is the cost for 100 kg woven bags, which is not used with whole ear storage. PICS bags lasting only one season are assumed to serve this function, but are considered storage costs.

Real crop income was then discounted by various hypothetical opportunity costs of capital (OCC) at the rates of 25%, 35%, 45%, and 55% annually. Table 15 presents the net gains from storage for each OCC. Due to the large fluctuation of prices from the immediate post-harvest period to the following pre-harvest period, storage in PICS bags could prove extremely profitable for these maize producers. Even discounting for an opportunity cost of 55%, a small producer in the 2007/08 season selling in the optimal month could have doubled their effective annual real maize income with the one-time use of a PICS storage bag. Although Sofagrain also provided consistent positive returns to storage, the nominal net gain on investment was 58% greater with PICS bags lasting only one season. Actellic will always underperform compared to Sofagrain, since losses are greater for all time intervals and insecticide prices are assumed to be the same.

Table 15: Derived Net Gains on Storage Investment in Mbeya, Tanzania for the optimal 2007/08 marketing season

	Sell Maize at Harvest	Storage of Maize with Traditional Methods					Storage of Maize with Hermetic PICS Bags
		Losses with No Insecticide			Sofagrain (50g/100kg)	Actellic Super (100g/100kg)	Lasting One Season
		20%	15%	10%			
Selling Period	May	February					
Adjusted Real Crop Income (1000 TZS)	7,651.82	8,385.70	10,335.47	12,501.85	15,078.81	13,351.58	18,749.50
OCC: 25%							
Net Gain on Storage (1000 TZS)	-	(700.84)	1,248.93	3,788.48	5,852.33	4,125.10	9,267.21
Return on Storage	-	(9.7%)	16.3%	49.5%	69.7%	49.1%	94.9%
OCC: 35%							
Net Gain on Storage (1000 TZS)	-	(1,274.73)	675.05	3,214.59	5,222.47	3,495.24	8,535.03
Return on Storage	-	(16.7%)	8.8%	42.0%	62.2%	41.6%	87.4%
OCC: 45%							
Net Gain on Storage (1000 TZS)	-	(1,848.62)	101.16	2,640.71	4,592.60	2,865.38	7,802.85
Return on Storage	-	(24.2%)	1.3%	34.5%	54.7%	34.1%	79.9%
OCC: 55%							
Net Gain from Storage (1000 TZS)	-	(2,422.50)	(472.73)	2,066.82	3,962.74	2,235.51	7,070.66
Return on Storage	-	(31.7%)	(6.2%)	27.0%	47.2%	26.6%	72.4%

Even assuming an omniscient producer could sell maize at annual price maximum month for five consecutive years, without storage technology they could expect negative economic returns of -2.7% to -21.7%.[10] With producers possessing high opportunity costs, returns on storage are positive for all technologies except Actellic Super. One-time use of PICS bags more than doubled storage returns compared to either recommended insecticides. The average cost of the PICS bag over two years is 50 shillings less than seasonal costs for all insecticide options assuming straight line depreciation and one marketing sack in the first year. With their high grain protection capacity, PICS bags lasting two years will, on average, provide the most profitable storage technology for farmers in Mbeya who can sell at the optimum price month each year.

Table 16: Average Return on Storage for Mbeya, Tanzania from 2003/04 to 2007/08 when selling in price maximum months

ROS (%) Summary with Varying OCCs	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High losses	Expected losses	Low losses			Lasting One Season	Lasting Two Seasons (average)
25%	(19.9%)	(2.7%)	19.5%	41.8%	12.4%	70.3%	88.8%
35%	(26.2%)	(9.1%)	13.2%	35.4%	6.0%	64.0%	82.4%
45%	(32.5%)	(15.4%)	6.9%	29.1%	(0.3%)	57.7%	76.0%
55%	(38.9%)	(21.7%)	0.5%	22.8%	(6.6%)	51.3%	69.6%

The assumption of the omniscient producer is unrealistic. A more realistic assumption is that producers would habitually sell 6 months after harvest (Table 17) or 8 months after harvest (Table 18). At 6 months after harvest, storage is not profitable in almost all of the scenarios with the exception of PICS bags used for 2 years and an OCC of 35% or below. At 8 months after harvest, PICS bags with single-year use become profitable and the only other profitable technology is Sofagrain when OCC is 35% or below.

The disparity between returns to storage at the six and eight month intervals underscores that producers need to store for long periods to recover their investment costs and compensate for any price discounts for grain damage.

[10] Which is modeled to result in 20% dry weight losses for long-term storage of 9-12 months.

Table 17: Average Return on Storage for Mbeya, Tanzania from 2003/04 to 2007/08 when always selling six months after harvest

Six Month ROS (%) Summary with Varying OCCs	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High losses	Expected losses	Low losses			Lasting One Season	Lasting Two Seasons (average)
25%	(61.0%)	(48.7%)	(32.7%)	(21.5%)	(31.5%)	(5.3%)	5.5%
35%	(66.0%)	(53.7%)	(37.7%)	(26.5%)	(36.5%)	(10.3%)	0.5%
45%	(71.0%)	(58.7%)	(42.7%)	(31.5%)	(41.5%)	(15.3%)	(4.5%)
55%	(76.0%)	(63.7%)	(47.7%)	(36.5%)	(46.5%)	(20.3%)	(9.5%)

Table 18: Average Return on Storage for Mbeya, Tanzania from 2003/04 to 2007/08 when always selling eight months after harvest

Eight Month ROS (%) Summary with Varying OCCs	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High losses	Expected losses	Low losses			Lasting One Season	Lasting Two Seasons (average)
25%	(44.7%)	(27.9%)	(6.0%)	9.2%	(4.6%)	29.7%	44.7%
35%	(51.4%)	(34.6%)	(12.6%)	2.5%	(11.2%)	23.1%	38.1%
45%	(58.0%)	(41.2%)	(19.3%)	(4.1%)	(17.9%)	16.4%	31.4%
55%	(64.7%)	(47.9%)	(26.0%)	(10.8%)	(24.6%)	9.7%	24.7%

Nakuru, Kenya

The Kenyan market region of Nakuru is a region of relatively low maize wholesale price fluctuation, with an average high/low price month ratio of 1.64 from 1994/95 to 2007/08 (Chapoto and Jayne 2010). This ratio is 19.2% lower than the high/low price month ratio in Mbeya. Comparing the net returns to storage across the two regions will highlight that a necessary condition for profitable storage is substantial price seasonailty. As Table 19 displays, upward maize price movement across the marketing season is relatively slow and mild. FEWS data reports the long-rain maize harvest in the Kenyan grain basket spans October to February. The “harvest” month designated by Chapoto and Jayne (2010) may be flexible across these four months which could potentially, albeit mildly, change profitability outcomes. As specific historical harvest data was not available for the Nakuru region, this analysis assumes November was the harvest month.

Table 19: Derived farm-gate prices in the Nakuru, Kenya marketing region (1000 KES/Mt)

Nakuru	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
2003/04	12.40	11.33	13.67	15.33	16.83	17.12	17.02	14.49	16.67	16.04	14.53	14.61
2004/05	14.11	14.26	13.55	12.84	11.66	12.50	13.08	12.50	12.90	11.25	13.18	12.52
2005/06	12.06	12.36	12.00	11.75	10.29	11.43	13.07	14.39	14.66	13.63	12.50	11.38
2006/07	10.45	9.32	8.21	8.33	9.71	9.86	10.22	9.92	9.95	9.64	9.98	10.32
2007/08	9.87	9.57	9.35	9.17	9.38	10.91	12.74	12.32	11.76	12.77	15.78	14.86

Source: Adapted from Chapoto and Jayne (2010) with marketing margin from Kirimi et al. (2010)

The absence of large price fluctuations in this marketing region makes even the most effective grain protecting measures unprofitable when opportunity costs of capital are considered. Table 20 shows that even if producers could predict the profit-maximizing month to store and sell for five consecutive years, significant negative returns to storage would occur under almost every storage technology option. Only PICS bags utilized for two years provided low positive returns on storage, and only occurred when the opportunity cost of capital was extremely low. Since the best possible scenario could rarely provide storage returns, it is of little value to present the even lower storage for six or eight months after harvest.

The low returns to storage in Kenya may also provide evidence that marketing producers are exercising rational, profit maximizing behavior in the work of Renkow et al. (2004), who states that 83% of producers in Kenya sell maize within two months of harvest. In this marketing region, since selling grain immediately after harvest provides the greatest maize income, the introduction of storage technologies may be of small benefit for profit-maximizing maize marketers. It is possible, however, that focusing on producers in this region who store maize long-term for household consumption (and thus possessing a utility function in which food self-sufficiency may outweigh profit maximization) could benefit from storage technologies, but the cost-benefit analysis for these populations is outside of the scope of the current analysis.

Table 20: Returns on Storage in Nakuru, Kenya under Diverse Rates of Opportunity Costs of Capital (Price Maximum Month)

ROS (%) Summary with Varying OCCs	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High losses	Expected losses	Low losses			Lasting One Season	Lasting Two Seasons (average)
25%	(56.1%)	(47.3%)	(35.9%)	(22.9%)	(38.2%)	(3.9%)	3.5%
35%	(61.9%)	(53.1%)	(41.7%)	(28.7%)	(44.1%)	(9.7%)	(2.3%)
45%	(67.7%)	(58.9%)	(47.5%)	(34.6%)	(49.9%)	(15.6%)	(8.1%)
55%	(73.6%)	(64.8%)	(53.4%)	(40.4%)	(55.7%)	(21.4%)	(14.0%)

Beira, Mozambique

Table 21 indicates that retail prices in Beira follow a relatively predictable upward trend from the post-harvest period, generally peaking as expected before the next harvest season. The 2006/07 season is as an exception to this trend. This market has displayed a relatively high ratio of high/low priced months of 2.20 from 1994/95 to 2007/08 (Chapoto and Jayne, 2010) and potentially supports high returns on storage investments. Farm-gate prices are assumed to be 60% of final retail prices, based on recent data from Malawi (Jayne et al., 2010).

Table 21: Derived Farm-gate maize prices in the sourcing region of Beira, Mozambique (MZN/Mt)

Beira	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
2003/04	2374.2	2267.4	2277.6	2753.4	2973.6	3076.8	3232.8	3963.6	4101	4119.6	4307.4	2963.4
2004/05	2214.6	2279.4	2446.2	2625.6	2741.4	2670	2640.6	2820	2692.2	2575.2	2778.6	2261.4
2005/06	2140.8	2331.6	2776.2	3124.8	3905.4	4467	4919.4	5805.0	6363.6	6076.8	5941.8	3496.8
2006/07	2158.8	2191.2	2922.0	2862.0	2743.8	2415.0	2548.8	2586.6	2657.4	2659.8	2590.8	2395.2
2007/08	2147.4	2107.2	2532.0	2476.2	2821.8	3534.6	4863.6	4651.2	4485.0	4354.8	3793.2	2964.6

Source: Chapoto and Jayne (2010); margins from Jayne et al. (2010)

Even in the most idealized of storage scenarios, returns on storage are generally negative above low dry weight losses (>10%) when no storage technology is utilized (Table 22). Net gains to storage over 10% may be seen, however, in situations of lowest of dry weight losses and the lowest opportunity costs of capital. Actellic Super also failed to provide economic gains to populations with opportunity costs of capital of 45% or greater.

Sofagrain and the PICS bags provided the most consistent positive returns to storage. If PICS bags could be utilized for two years, the average return on storage would be 38.8% for populations with as high as 55% opportunity cost of capital. Thus, the model strongly suggests that this region could benefit greatly from improved storage capabilities, even under high opportunity costs of capital.

Table 22: Five-year average returns on storage (%) in the sourcing region of Beira, Mozambique when selling in the price maximum month

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(31.7%)	(12.1%)	13.4%	20.3%	10.6%	34.0%	56.3%
35%	(37.5%)	(18.0%)	7.6%	14.4%	4.7%	28.1%	50.4%
45%	(43.4%)	(23.8%)	1.7%	8.6%	(1.1%)	22.3%	44.6%
55%	(49.2%)	(29.6%)	(4.1%)	2.8%	(6.9%)	16.5%	38.8%

Average returns on storage increase with the duration of the storage period. Even with six months of storage, positive returns are seen utilizing Sofagrain and PICS bags for the populations with the lowest opportunity cost. PICS bags which are utilized for two consecutive seasons have positive returns for the entire modeled population.

Table 23: Returns to Storage (%) in the sourcing region of Beira, Mozambique for strict six months storage

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(44.3%)	(28.2%)	(7.2%)	7.2%	3.3%	14.8%	33.9%
35%	(49.3%)	(33.2%)	(12.2%)	2.2%	(1.7%)	9.8%	28.9%
45%	(54.3%)	(38.2%)	(17.2%)	(2.8%)	(6.7%)	4.8%	23.9%
55%	(59.3%)	(43.2%)	(22.2%)	(7.8%)	(11.7%)	(0.2%)	18.9%

Table 24: Returns to Storage (%) in the sourcing region of Beira, Mozambique for strict eight months storage

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(40.3%)	(22.4%)	1.0%	5.1%	2.3%	25.1%	46.3%
35%	(46.9%)	(29.0%)	(5.7%)	(1.6%)	(4.3%)	18.4%	39.7%
45%	(53.6%)	(35.7%)	(12.3%)	(8.2%)	(11.0%)	11.7%	33.0%
55%	(60.3%)	(42.4%)	(19.0%)	(14.9%)	(17.7%)	5.1%	26.3%

Blantyre, Malawi

Real retail prices and, by assumption, farm-gate prices in Malawi generally followed a predictable increasing trend in the 2003-2008 marketing seasons. The ratios of high/low month prices vary from 1.54 to 5.10, however, indicating great differences in the intensity of intra-seasonal real price growth. Chapoto and Jayne (2010) make an argument that the infrastructural disconnect between northern and southern Mozambican regions through much of the 1994/95 to 2007/08 provides a strong explanation for higher trade volumes and price covariance between markets in northern and central Mozambique and markets in Malawi. Malawi is much more densely populated than northern Mozambique, however, and maize constitutes an extremely common and important crop for small-scale producers (Jayne et al. 2010).

Table 25 displays that there is very strong upward movement of real prices throughout each marketing year, with the maximum monthly price occurring 6-9 months after the harvest period. Malawian markets displayed some of the highest high/low price month ratios in the set of markets examined by Chapoto and Jayne (2010). The Blantyre market had an average ratio of 2.65 for the 1994/95 to 2007/08 study period.

Table 25: Derived monthly real farm-gate maize prices in the Blantyre, Malawi region (in 1000 MKW/Mt)

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
2003/04	7.32	9.19	10.84	8.33	10.00	14.81	19.13	13.91	17.79	18.19	18.99	15.08
2004/05	11.85	13.74	14.33	16.15	16.31	14.67	13.73	17.32	14.96	14.94	11.26	11.93
2005/06	13.38	16.99	18.55	18.81	19.69	24.15	26.79	26.70	29.59	39.38	30.08	14.39
2006/07	10.89	12.79	13.87	13.95	12.94	14.32	14.07	15.45	20.67	21.74	9.76	7.94
2007/08	5.58	6.23	9.90	10.32	9.95	14.60	23.05	27.65	28.48	26.51	18.62	17.67

Results indicate that price fluctuations are large enough that in the most idealized marketing month selection, even storage of maize without the use of insecticides would provide positive returns to storage with expected loss levels. Table 26 demonstrates that the one-time use of PICS bags would provide greater returns than both insecticides, and extended use for a second season would provide returns of over 100% for producers at all modeled opportunity cost levels.

Table 26: Five-year average returns on storage (%) in the sourcing region of Blantyre, Malawi when selling in the price maximum month

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	2.9%	30.7%	67.0%	81.7%	51.3%	94.9%	129.9%
35%	(4.0%)	23.9%	60.1%	74.9%	44.5%	88.0%	123.1%
45%	(10.8%)	17.0%	53.3%	68.0%	37.6%	81.2%	116.3%
55%	(17.6%)	10.2%	46.5%	61.2%	30.8%	74.4%	109.4%

Sale strictly on the eighth month of storage provides returns which are very similar to the idealized scenario in this market. Farmers selling only after six months of storage would still expect to see consistent positive gains on storage above 20% in all opportunity cost populations when any storage technology is utilized.

Table 27: Returns to Storage in the sourcing region of Blantyre, Malawi for strict six months of storage

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(18.3%)	3.8%	32.6%	32.8%	29.5%	54.4%	82.8%
35%	(23.3%)	(1.2%)	27.6%	27.8%	24.5%	49.4%	77.8%
45%	(28.3%)	(6.2%)	22.6%	22.8%	19.5%	44.4%	72.8%
55%	(33.3%)	(11.2%)	17.6%	17.8%	14.5%	39.4%	67.8%

Table 28: Returns to Storage in the sourcing region of Blantyre, Malawi for strict eight months storage

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(7.3%)	18.2%	51.5%	51.5%	47.7%	75.6%	108.3%
35%	(13.9%)	11.6%	44.8%	44.8%	41.0%	69.0%	101.7%
45%	(20.6%)	4.9%	38.1%	38.2%	34.3%	62.3%	95.0%
55%	(27.3%)	(1.8%)	31.5%	31.5%	27.7%	55.6%	88.3%

Such strong net gains to storage modeled in Tables 27, 28, and 29 suggest that all rational producers with an opportunity cost of capital of even 50% annually would engage in long-term storage. However, few small producers actually engage in long-term storage of grain intended for market. There are three potential reasons small producer may not store grain. First, they may face opportunity costs of capital that are higher than those considered in this model. Second, small producers may have little or no access to credit which would necessitate the immediate sale of grain to pay debts. Finally, the storage losses and/or the technology prices assumed in this model may not be correct.

Western Africa

Tamale, Ghana

The city of Tamale is the regional and administrative capital of Ghana's northern region. Tamale is located in a pocket of large maize production displayed and contains one of the largest wholesale markets in the region (FAO, 2005).

WFP bulletins from 2010 report the year's main harvest period as October and November. An early harvest period begins in August, which explains early price declines (WFP 2010). WFP bulletins from the fourth quarter of 2009 also report the harvest generally ending by late October (WFP 2009). Assuming these two years represent the general trend, the model will incorporate the general reference harvest month as October.

Figure 6 displays the "well behaved" nominal five-year average wholesale price patterns, with troughs in the post-harvest period and peaks in the months just preceding the following harvest. Limited individual year data show contrasts from the more volatile pre- and post- harvest season in 2009 to a much more stable period in the past calendar year of September 2009 – 2010.

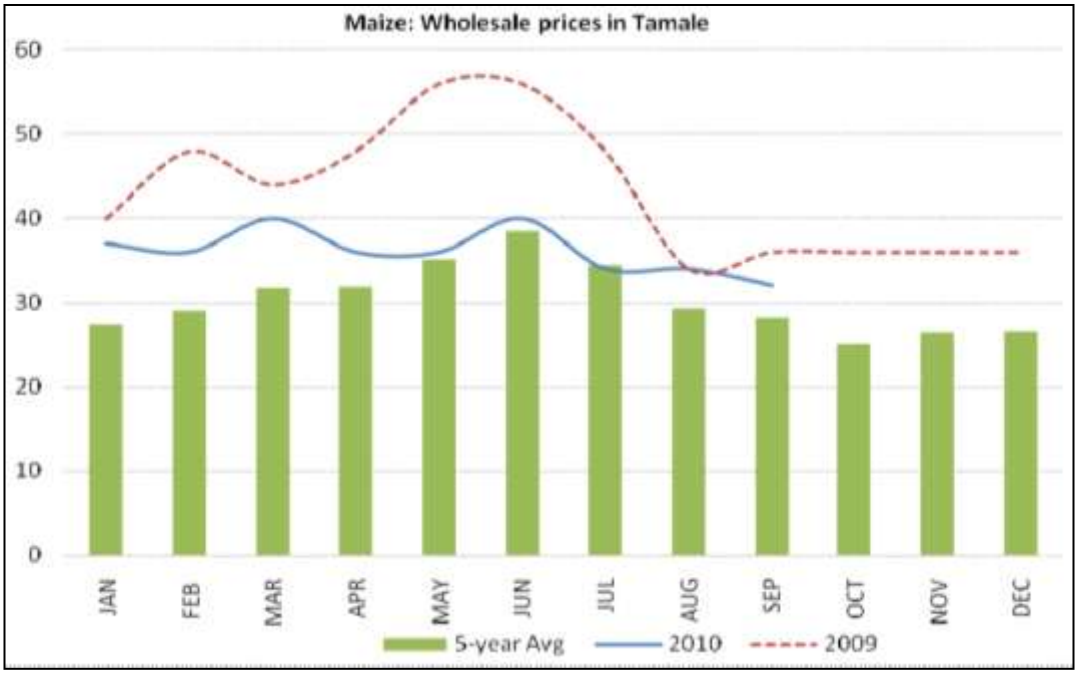

Figure 6: Nominal Wholesale Maize Prices in the Tamale market, Northern Ghana (cedi/100kg)
Graphic Source: WFP (2010)
Data Source: Cited in bulletin as MoFA/SRID

Using the estimation method described in the methodology section, Table 29 illustrates five-year average wholesale prices and corresponding farm-gate level prices. The low price month is October and the high price month is June. Marketing margins are assumed to remain constant throughout the year.

Table 29: Estimated monthly wholesale prices for Tamale market, Ghana (nominal five-year averages) (cedi/100 kg)

Wholesale Prices											
Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
25.25	26.5	26.6	27.5	29.0	31.75	31.9	35.0	38.5	34.5	29.4	28.3
Derived Farm-gate Prices											
Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
16.83	17.67	17.73	18.33	19.33	21.17	21.27	23.33	25.67	23.00	19.6	18.87

Note: Farm-gate prices assumed to be 66.6% of wholesale prices in Ghana (Brooks, Croppenstedt, and Aggrey-Fynn, 2007)

Profitability increases dramatically when increasing the storage period after harvest from six months (Table 30) to eight months (Table 31) to attain the maximum nominal price. As shown in Table 30, positive returns on storage are only seen with PICS bags use among populations with the lowest opportunity cost of capital in six months of storage. Table 31 displays that Sofagrain insecticide also becomes profitable at eight months of storage for populations with an OCC of 25%. PICS bags showed positive returns for all modeled populations at eight months, peaking at 19.2% for one time use and an average 28.4% for two years of use among producers with the lowest OCCs.

Table 30: Return on Storage in Tamale, Ghana when strictly selling six months after harvest (April)

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(61.0%)	(48.9%)	(33.1%)	(11.2%)	(20.8%)	0.1%	7.8%
35%	(66.0%)	(53.9%)	(38.1%)	(16.2%)	(25.8%)	(4.9%)	2.6%
45%	(71.0%)	(58.9%)	(43.1%)	(21.2%)	(30.8%)	(9.9%)	(2.5%)
55%	(76.0%)	(63.9%)	(48.1%)	(26.2%)	(35.8%)	(14.9%)	(7.7%)

Table 31: Return on Storage in Tamale, Ghana when strictly selling eight months after harvest (June, maximum price month)

OCC	No Storage Technology			Sofagrain	Actellic Super	PICS Bags	
	High Losses	Expected Losses	Low Losses			One Year Use	Two Year Use (Avg.)
25%	(53.9%)	(39.3%)	(20.2%)	4.7%	(5.4%)	19.2%	28.4%
35%	(60.6%)	(46.0%)	(26.9%)	(2.0%)	(12.1%)	12.6%	21.6%
45%	(67.3%)	(52.6%)	(33.5%)	(8.6%)	(18.7%)	5.9%	14.7%
55%	(73.9%)	(59.3%)	(40.2%)	(15.3%)	(25.4%)	-0.8%	7.9%

Regional Summaries

On a per-country basis, the annual potential increase in annual maize profits with PICS bags used for only one year is estimated in Tables 32-38, based on historical market price fluctuations. Locations are assessed based on an outlook of eight months after the harvest month, a conservative estimate based on the Eastern and Southern African average of seven months between high/low price months (Chapoto and Jayne, 2010). Differences in returns to storage between countries will represent both the intensity of price increases over the year and the ratio of the value of 100kg of maize to the estimated price of the PICS bag in that region. All other factors are held constant.

Results presented in tables 32-35 indicate that the very large average price increases of 84.7% in Beira and 127.4% in Blantyre suggest that PICS bags, even only used once, could provide returns over 20% to all producers with opportunity costs under 45% annually. Tables 36-38 show that 50% increase in the maize price between harvest and after eight months of storage would provide economic returns over 10% to producers in Mbeya and Tamale with relatively low opportunity costs of capital. Average price increases of 52.5% in Tamale and 44.7% in Mbeya indicate that large storage returns are possible in an average year. A price increase of 70% over eight months after harvest would provide returns over 10% to producers in every study market. As the average price increase over eight months (in the study period 2003/04 to 2007/08) was only 12.0% in Nakuru, tables 39 and 40 display that it is very unlikely that economic returns to storage would be positive in this region.

Table 32: Possibility Frontier for Returns on Storage in Beira, Mozambique from maize stored for eight months (PICS bag, one time use; Average harvest prices for 2003/04-2007/08 seasons)

OCCs	Market Price Increase from Harvest								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
25%	(24.5)	(16.8)	(9.1)	(1.5)	6.2	13.9	21.6	29.3	36.9
35%	(31.2)	(23.5)	(15.8)	(8.1)	(0.4)	7.2	14.9	22.6	30.3
45%	(37.8)	(30.2)	(22.5)	(14.8)	(7.1)	0.6	8.3	15.9	23.6
55%	(44.5)	(36.8)	(29.1)	(21.5)	(13.8)	(6.1)	1.6	9.3	16.9
65%	(51.2)	(43.5)	(35.8)	(28.1)	(20.4)	(12.8)	(5.1)	2.6	10.3
75%	(57.8)	(50.2)	(42.5)	(34.8)	(27.1)	(19.4)	(11.7)	(4.1)	3.6
85%	(64.5)	(56.8)	(49.1)	(41.5)	(33.8)	(26.1)	(18.4)	(10.7)	(3.1)
95%	(71.2)	(63.5)	(55.8)	(48.1)	(40.4)	(32.8)	(25.1)	(17.4)	(9.7)
105%	(77.8)	(70.2)	(62.5)	(54.8)	(47.1)	(39.4)	(31.7)	(24.1)	(16.4)

Table 33: Yearly Summary: Returns on Storage in Beira, Mozambique from maize stored for eight months (PICS bag, one time use)

	2003/04	2004/05	2005/06	2006/07	2007/08	Avg
Market Price Increase from Harvest (%)	72.7	21.6	197.3	23.1	108.9	84.7
Return on Storage with PICS bag (1 year use; OCC 25%)	18.2	(23.2)	110.1	(22.6)	42.8	25.1
Return on Storage with PICS bag (1 year use; OCC 55%)	(1.8)	(43.2)	90.1	(42.6)	22.77	5.1

Table 34: Possibility Frontier for Returns on Storage in Blantyre, Malawi from maize stored for eight months (PICS bag, one time use; Average harvest prices for 2003/04-2007/08 seasons)

OCCs	Market Price Increase from Harvest								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
25%	(24.1)	(16.4)	(8.7)	(1.0)	6.7	14.4	22.1	29.8	37.5
35%	(30.8)	(23.1)	(15.4)	(7.7)	0.0	7.7	15.4	23.2	30.9
45%	(37.5)	(29.8)	(22.1)	(14.4)	(6.6)	1.1	8.8	16.5	24.2
55%	(44.1)	(36.4)	(28.7)	(21.0)	(13.3)	(5.6)	2.1	9.8	17.5
65%	(50.8)	(43.1)	(35.4)	(27.7)	(20.0)	(12.3)	(4.6)	3.2	10.9
75%	(57.5)	(49.8)	(42.1)	(34.4)	(26.6)	(18.9)	(11.2)	(3.5)	4.2
85%	(64.1)	(56.4)	(48.7)	(41.0)	(33.3)	(25.6)	(17.9)	(10.2)	(2.5)
95%	(70.8)	(63.1)	(55.4)	(47.7)	(40.0)	(32.3)	(24.6)	(16.8)	(9.1)
105%	(77.5)	(69.8)	(62.1)	(54.4)	(46.6)	(38.9)	(31.2)	(23.5)	(15.8)

Table 35: Yearly Summary: Returns on Storage in Blantyre, Malawi from maize stored for eight months (PICS bag, one time use)

	2003/04	2004/05	2005/06	2006/07	2007/08	Avg
Market Price Increase from Harvest (%)	143.2	26.2	121.1	89.8	410.3	158.1
Return on Storage with PICS bag (1 year use; OCC 25%)	61.2	(13.9)	67.3	35.5	228.1	75.6
Return on Storage with PICS bag (1 year use; OCC 55%)	41.2	(33.9)	47.3	15.5	208.1	55.6

Table 36: Possibility Frontier for Returns on Storage in Mbeya, Tanzania from maize stored for eight months (PICS bag, one time use; Average harvest prices for 2003/04-2007/08 seasons)

OCCs	Market Price Increase from Harvest								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
25%	(13.6)	(5.0)	3.6	12.2	20.8	29.4	38.0	46.6	55.2
35%	(20.2)	(11.6)	(3.0)	5.6	14.2	22.7	31.3	39.9	48.5
45%	(26.9)	(18.3)	(9.7)	(1.1)	7.5	16.1	24.7	33.3	41.9
55%	(33.6)	(25.0)	(16.4)	(7.8)	0.8	9.4	18.0	26.6	35.2
65%	(40.2)	(31.6)	(23.0)	(14.4)	(5.8)	2.7	11.3	19.9	28.5
75%	(46.9)	(38.3)	(29.7)	(21.1)	(12.5)	(3.9)	4.7	13.3	21.9
85%	(53.6)	(45.0)	(36.4)	(27.8)	(19.2)	(10.6)	(2.0)	6.6	15.2
95%	(60.2)	(51.6)	(43.0)	(34.4)	(25.8)	(17.3)	(8.7)	(0.1)	8.5
105%	(66.9)	(58.3)	(49.7)	(41.1)	(32.5)	(23.9)	(15.3)	(6.7)	1.9

Table 37: Yearly Summary: Returns on Storage in Mbeya, Tanzania from maize stored for eight months (PICS bag, one time use)

	2003/04	2004/05	2005/06	2006/07	2007/08	Avg
Market Price Increase from Harvest (%)	54.8	60.0	154.9	(46.3)	143.9	73.5
Return on Storage with PICS bag (1 year use; OCC 25%)	15.1	23.2	94.2	(67.0)	83.2	29.7
Return on Storage with PICS bag (1 year use; OCC 55%)	(4.9)	3.2	74.2	(87.0)	63.2	9.7

Table 38: Possibility Frontier for Returns on Storage in Tamale, Ghana from maize stored for eight months (PICS bag, one time use; Average harvest prices for 2003/04-2007/08 seasons) (insufficient data to perform yearly analysis)

OCCs	Market Price Increase from Harvest								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
25%	(9.7)	(0.8)	8.1	17.0	25.9	34.8	43.7	52.6	61.5
35%	(16.4)	(7.5)	1.4	10.3	19.2	28.1	37.0	46.0	54.9
45%	(23.1)	(14.2)	(5.3)	3.7	12.6	21.5	30.4	39.3	48.2
55%	(29.7)	(20.8)	(11.9)	(3.0)	5.9	14.8	23.7	32.6	41.5
65%	(36.4)	(27.5)	(18.6)	(9.7)	(0.8)	8.1	17.0	26.0	34.9
75%	(43.1)	(34.2)	(25.3)	(16.3)	(7.4)	1.5	10.4	19.3	28.2
85%	(49.7)	(40.8)	(31.9)	(23.0)	(14.1)	(5.2)	3.7	12.6	21.5
95%	(56.4)	(47.5)	(38.6)	(29.7)	(20.8)	(11.9)	(3.0)	6.0	14.9
105%	(63.1)	(54.2)	(45.3)	(36.3)	(27.4)	(18.5)	(9.6)	(0.7)	8.2

Table 39: Possibility Frontier for Returns on Storage in Nakuru, Kenya from maize stored for eight months (PICS bag, one time use; Average harvest prices for 2003/04-2007/08 seasons)

OCCs	Market Price Increase from Harvest								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
25%	(9.32)	(0.37)	8.57	17.52	26.47	35.41	44.36	53.30	62.25
35%	(15.98)	(7.04)	1.91	10.85	19.80	28.74	37.69	46.64	55.58
45%	(22.65)	(13.70)	(4.76)	4.19	13.13	22.08	31.02	39.97	48.92
55%	(29.32)	(20.37)	(11.43)	(2.48)	6.47	15.41	24.36	33.30	42.25
65%	(35.98)	(27.04)	(18.09)	(9.15)	(0.20)	8.74	17.69	26.64	35.58
75%	(42.65)	(33.70)	(24.76)	(15.81)	(6.87)	2.08	11.02	19.97	28.92
85%	(49.32)	(40.37)	(31.43)	(22.48)	(13.53)	(4.59)	4.36	13.30	22.25
95%	(55.98)	(47.04)	(38.09)	(29.15)	(20.20)	(11.26)	(2.31)	6.64	15.58
105%	(62.65)	(53.70)	(44.76)	(35.81)	(26.87)	(17.92)	(8.98)	(0.03)	8.92

Table 40: Yearly Summary: Returns on Storage in Nakuru, Kenya from maize stored for eight months (PICS bag, one time use)

	2003/04	2004/05	2005/06	2006/07	2007/08	Avg
Market Price Increase from Harvest (%)	34.4	(8.6)	21.5	(4.8)	19.2	12.4
Return on Storage with PICS bag (1 year use; OCC 25%)	4.4	(33.4)	(7.5)	(32.4)	(11.9)	(16.2)
Return on Storage with PICS bag (1 year use; OCC 55%)	(15.6)	(53.4)	(27.5)	(52.4)	(31.9)	(36.2)

Conclusions

This analysis has demonstrated that, under reasonable assumptions, PICS bags have very high potential to increase maize income within Eastern, Southern, and Western Africa. The largest potential income gains could occur in regions with LGB infestations, though rigorous verification of PICS efficacy with LGB is still underway. In long-term storage, this analysis shows that PICS bags are more cost-effective than both leading chemical grain protectants. Some market regions show more potential than others. Market price fluctuations throughout the year are necessary for economic storage returns, and regions with more stable price patterns such as Kenya may be less likely to invest in storage technology when the producers have the objective of maximizing annual profit from maize sales. Producers who have an objective of meeting household food security needs may be willing to invest in storage technology regardless of market returns to storage. In the markets investigated within Ghana, Tanzania, Malawi, and Mozambique, however, the combination of large losses from LGB and pronounced seasonal increases in market prices indicate much higher potential adoption of PICS technology.

Price patterns will vary annually in any market, and no region modeled provides positive storage returns throughout the entire five-year period. When selecting market zones for introducing PICS bags, it will be important to identify market zones where positive returns to storage occur most frequently. This analysis has also demonstrated that significant returns in some years can more than compensate for occasional years of negative returns, and thus suggests that average returns are the best indicators of investment profitability. As all markets modeled except Nakuru, Kenya demonstrated average positive returns, there is high potential benefit from PICS technology in the region.

Household investment criteria for storage technology may also extend beyond marketing strategies. Some households never market, but still purchase insecticides to protect family maize stocks. As maize grain damage may affect each household's utility differently, the value of storage protection is much more difficult to determine for non-marketing producers. More research is needed to estimate these parameters and provide analysis for potential technology adoption by these non-marketing producers.

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