Profitability of Hermetic Purdue Improved Crop Storage (PICS) Bags for African Common Bean Producers

3 authors:

Michael S. Jones
North Carolina State University

Corinne E. Alexander
Purdue University

James Lowenberg-DeBoer
Harper Adams University

Profitability of Hermetic Purdue Improved Crop Storage (PICS) Bags for African Common Bean Producers

by

Michael Jones, Corinne Alexander and James Lowenberg-DeBoer

Working Paper #11-6

November 2011

Dept. of Agricultural Economics

Purdue University

Profitability of Hermetic Purdue Improved Crop Storage (PICS) Bags for African Common Bean Producers

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
Working Paper #11-6
November 2011

Abstract

Bruchid species like *Acanthoscelides obtectus* (Coleoptera) and *Zabrotes subfasciatus* (Coleoptera) cause significant storage losses for African common bean producers. The value of storage protection to a market-oriented farmer is a function of price seasonality, value loss prevention, and their respective opportunity costs of capital. Evidence suggests that hermetic technologies like Purdue Improved Crop Storage (PICS) bags could be effective against key legume storage pests, but sustainable technology introduction requires that it be profitable for producers. While PICS bag effectiveness against these specific common bean bruchid species is still under investigation, this analysis references dry weight loss figures from life science articles and builds on previous value loss research to provide a model for potential competitiveness and technology adoption. PICS bag profitability with one and two years use are compared with estimated profitability of leading insecticide Actellic Super (permethrin (0.3%) + pirimiphos-methyl (1.6%)), weekly solar disinfestation and sieving, and the botanicals *A.indica*, *T. minuta*, *C. lusitanica*, and *C. ambrosiodes*. The Tanzanian market regions of Mbeya, Songea, Arusha, and Kigoma are analyzed. Results show competitive profitability of PICS bags with conservative loss estimates for alternative storage technologies, with high potential for adoption in Mbeya, Songea, and Kigoma.

Keywords: agricultural pests, technology adoption, Phaseolus vulgaris, hermetic storage, storage economics

JEL Codes: Q16, Q13, O33

Problem Statement

The common bean (*Phaseolus vulgaris)* has significant nutritional and economic importance in many regions of Eastern and Southern Africa (Giga et al., 1992; Wortmann et al., 1998; FAO STAT, 2010). In this region, bean consumption alone comprises the third largest source of calories and the second greatest source of dietary protein (Hillocks et al., 2006). In 1998, researchers estimated almost 40% of total African bean production was marketed, with an average annual value of $452 million USD (Wortmann et al., 1998). Production has since grown from 1.96 million tons in 1999 to over 2.5 million tons in 2008 (FAOSTAT, 2010). Price seasonality is also very pronounced in many regions, with ratios of average annual price increases estimated between 17% – 59% in Tanzania, 16% – 34% in Kenya, and 31% – 100% in Uganda (FEWS NET, 2010b,c,d). Effective storage of this increasingly important crop could therefore provide significant economic returns to producers.

On-farm storage is short term though, which is largely accredited to severe losses due to pests *A. obtectus and Z. subfaciatus* in inadequately protected grain stores (Giga et al., 1992). Average dry weight losses in unprotected stores range from 10-40% in less than six months, and up to 70% grain damage rates are recorded in the same time period (Kiula and Karel, 1985; Khamala, 1978; Paul et al., 2009). Grain damage, generally defined as insect emergence holes in beans, results in significant price discounts, reaching up to a 2.3% decrease in price for every hole per 100 beans (Mishili et al., 2011). To combat these storage pests, many extension offices promote pest control strategies such as insecticide use and/or solar disinfection, though certain botanicals show moderate potential as storage treatments (Songa and Rono, 1998; Paul et al., 2009). However, the moderate effectiveness of botanicals as storage protectants, the possible health concerns from insecticide use, and the labor intensity of solar disinfection practices provide shortcomings in their efficacy for common bean storage (Songa and Rono, 1998; Paul et al., 2009). A new technology, Purdue Improved Crop Storage (PICS) triple-layer hermetic storage bags, may provide an improved alternative for insecticide-free, long-term storage of common beans with minimal grain damage (Murdock et al., 2003; Hell et al., 2010; Ognakossan et al., 2010). This analysis evaluates the cost-effectiveness of PICS bags against other storage technologies available to small producers in Eastern and Southern Africa.

<u>Introduction</u>

Worldwide, the common dry bean (*Phaseolus vulgaris* L.) is the most economically and nutritionally important legume for human consumption (Jones, 1999). A major staple crop in Eastern and Southern Africa, the common bean is estimated as the third-largest source of calories and the second-largestest source of dietary protein (Hillocks et al., 2006). Dry beans are relatively inexpensive and complement the amino acids provided by maize and rice, making them a key factor in fighting malnutrition (Pachico, 1993; WMO, 1992). Known as the “poor man’s meat” in Eastern Africa, common beans are among several of protein-rich plant sources commonly cultivated and consumed by low-income households across the region (Wortmann et al., 1998). Figure 1 displays the relative nutritive importance of dry beans among common protein-rich plants throughout the sub-continent.

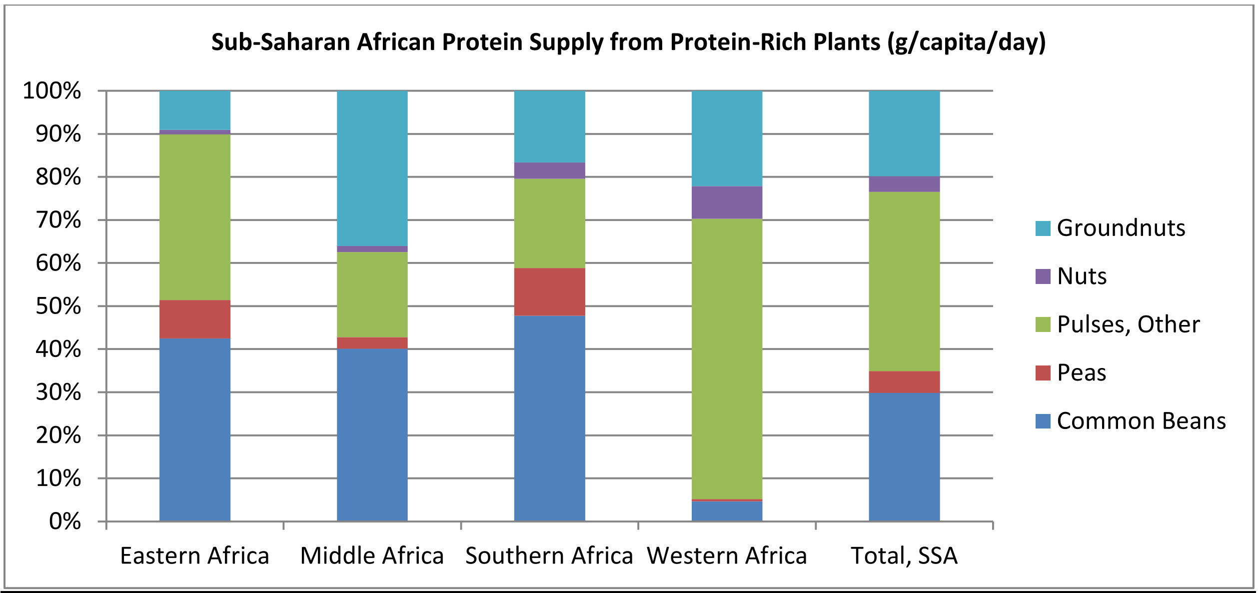

Figure 1: Relative Importance of Protein Supply from Various Different Protein-Rich Plants
Source: FAOSTAT

East African production of common beans has grown from 1.96 million tons in 1999 to over 2.5 million tons in 2008 (FAOSTAT, 2010). Over 96 bean production areas are defined in the African sub-continent, though the sub-humid regions of East Africa encompass 39% of all African production (Wortmann et al., 1998). Throughout the last decade in Eastern Africa, producers in Uganda, Tanzania, and Kenya alone represented between 59.3% (2001) and 67.1% (2006) of regional production, as displayed in Figure 2 (FAOSTAT, 2010). Rwanda has also recently surpassed Kenya in production with 308,000 tons in 2008 (ibid).

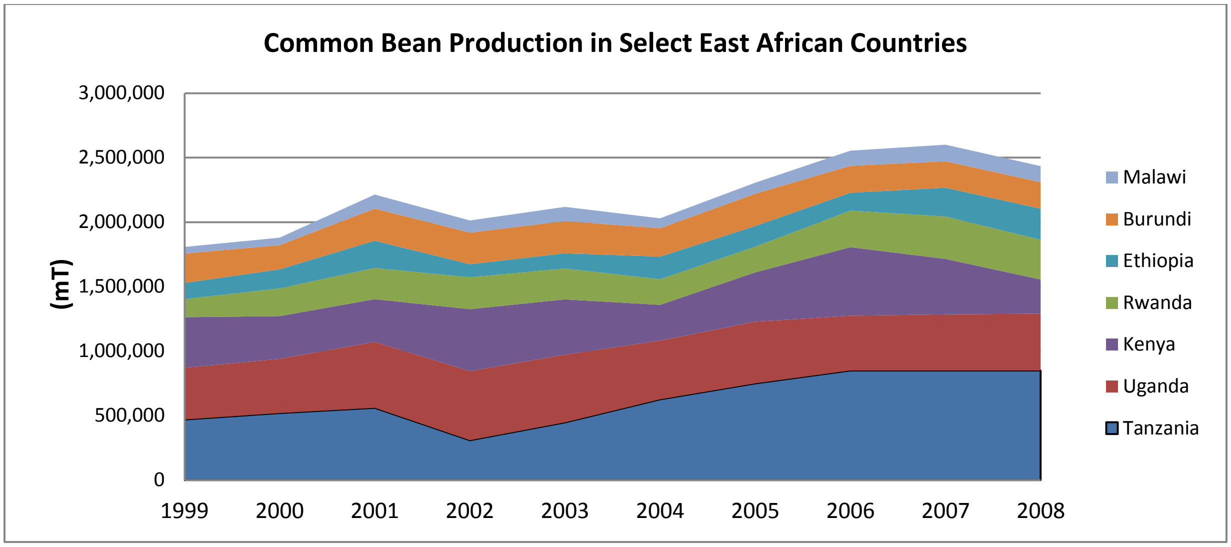

Figure 2: Common Bean Production in Select East African Countries
Source: FAOSTAT

Women generally dominate bean production and the crop is extremely important in subsistence farming households (Wortmann et al., 1998). In 1998, researchers also estimated that nearly 40% of total African bean production was marketed, with an average annual value of $452 million USD (ibid). Marketing rates are known to vary greatly among growing regions, with particularly high rates of marketing (≥ 60%) in Northern and Northwestern Tanzania as well as Central and Western Kenya, and particularly low marketing rates (≤ 20%) in Rwanda and Burundi (ibid). Giga et al. (1992) reported that among studied producers in Uganda, Tanzania, and Zimbabwe, between 55-82% of beans are marketed, 9-38% kept for household use, and 9-34% retained for seed. Marketing rates were highest across Uganda, at 66-84% (ibid).

Figure 3 illustrates notable bean trade routes in East Africa. Large flows of domestic trade occur between the southern highlands of Tanzania to Dar es Salaam and from Western and Eastern Kenya to Nairobi. While the vast majority of bean marketing occurs domestically, exports from Ethiopia, Uganda, Kenya, Rwanda, and Tanzania totaled 123,265 tons in 2008, with a value of over $79 million USD (Wortmann et al., 1998; FAO TradeSTAT, 2010).

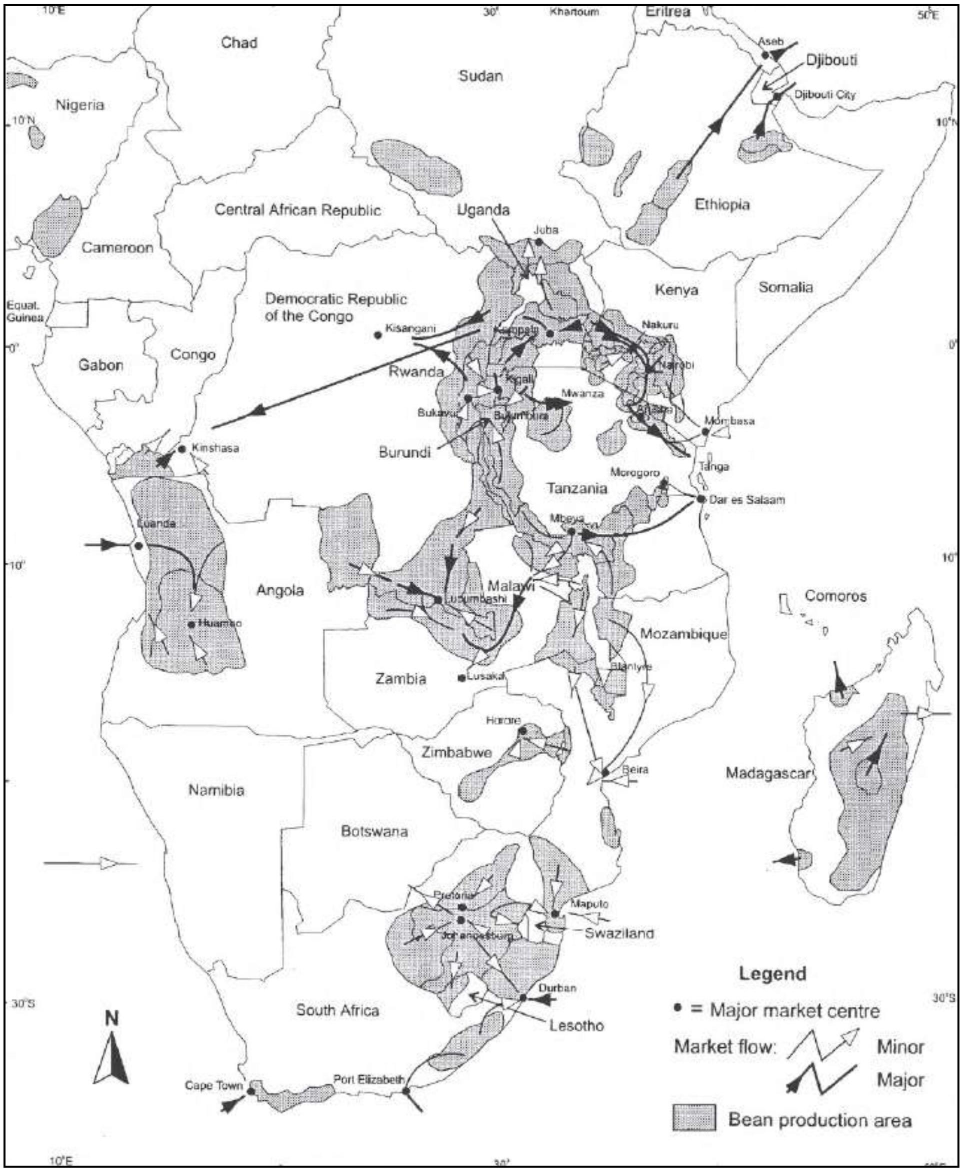

Figure 3: Common Bean Production and Trading Patterns in Eastern Africa
Source: Wortmann et al. (1998)

Drivers of Common Bean Prices

Price Seasonality

Price seasonality is generally driven by regional harvesting periods, which are heavily dependent on rainfall and climate patterns. Wortmann et al. (1998) designated fourteen African "bean-growing environments" depending on rainfall patterns, soil types, and altitude and latitude range. Planting and harvest periods, as well as post-harvest marketing strategies, may vary considerably among these growing environments. In the Ugandan and northern Tanzanian highlands, farmers cultivate two bean crops annually due to bimodal rainfall patterns, meaning two annual rainy seasons (Giga et al., 1992). In the lowland regions of northern Tanzania, farmers have also reported growing a third bean crop to provide seed for planting, as bruchid damage prevents reliable long-term storage of seed (ibid).

In all regions of Tanzania, beans are planted in the middle of major rainfall periods and harvested in the middle of the following dry-cool period (Nchimi-Msolla and Misangu, 2002). Farmers do not plant in the beginning of the rainy season to avoid early flowering during periods of heavy rain, and thus prevent subsequent dropping of flowers (ibid). Table 1 presents an estimation of planting and harvest schedules in Tanzania's diverse rainfall zones, based on planting strategies provided by Nchimi-Msolla and Misangu (2002) and rainfall forecast patterns for 2010 and 2011 from FEWS NET (2010a).

Table 1: Estimated Bean Planting and Harvest Patterns in Tanzania based on Rainy and Dry Seasons

<table>
<tr><th colspan="13">Estimated Tanzanian Bean Planting and Harvest Patterns, based on Rainy and Dry Seasons</th></tr>
<tr><th>Regions</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>June</th><th>July</th><th>Aug</th><th>Sept</th></tr>
<tr><td rowspan="2">Unimodal Zone</td><td></td><td colspan="3">Msimu Rains</td><td>Dry Spell</td><td colspan="3">Msimu Rains</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>P</td><td></td><td></td><td colspan="3">H</td><td></td><td></td></tr>
<tr><td rowspan="2">Bimodal Zone</td><td colspan="3">Vuli Rains</td><td></td><td></td><td colspan="3">Masika Rains</td><td></td><td></td><td></td><td>Vuli Rains</td></tr>
<tr><td colspan="2">P</td><td></td><td>H</td><td></td><td></td><td>P</td><td></td><td>H</td><td></td><td></td><td></td></tr>
</table>

Source: Rainfall for 2010, 2011- FEWS (2010a); Planting and Harvest periods are based on planting and harvest around rain patterns- Nichimba (2002)
Abbreviations: (P)- Planting; (H)- Harvesting

Two annual harvest periods may provide more steady market supply, contributing to less pronounced annual price fluctuations. For example, Table 2 displays less pronounced (nominal) high/low month price ratios in the bimodal zones of Arusha and Dar es Salaam, at 1.17 and 1.21 respectively (FEWSNET, 2010b). In contrast, other Tanzanian regions display high/low month price ratios of 1.33 to 1.59, with the highest fluctuations in Kigoma, on the northwest border with Burundi. In Kenya, bean price fluctuations are relatively low compared to neighboring countries, which is characteristic of many Kenyan grain and pulse price patterns (FEWSNET, 2010b,c,d). The Ugandan capital, Kampala, has the highest seasonal price fluctuation in the available data, followed by the northern Ugandan city of Gulu.

Table 2: Estimated ratio of high/low nominal price months

Ratio of High/Low Price Months for Common Beans in Select East African Countries					
Tanzania		Kenya		Uganda	
Arusha	1.174	Kitui	1.168	Lira	1.312
Dar es Salaam	1.211	Nairobi	1.201		
Dodoma	1.333	El Doret	1.275	Gulu	1.684
Mbeya	1.391	Kisimu	1.335		
Songea	1.461	-	-	Kampala	2.000
Kigoma	1.587	-	-		

Source: FEWS (2010b,c,d)

Common Bean Hedonic Price Formation and Consumer Preferences

Consumer preferences have been documented throughout Africa regarding common bean size, cooking time, grain damage, discoloring, variety, and degree of uniformity in a sample (Mishili et al., 2011; Wortmann et al., 1998). The degree of preference for certain product attributes is reflected in the premium consumers are willing to pay for these attributes. Likewise, the degree of distaste for product attributes will determine the magnitude of the discount. In Eastern Africa, large and medium sized seeds are preferred (Wortmann et al., 1998; Mishili et al., 2011). However, these preferences vary in intensity across production areas and are less pronounced among lower-income consumers (Wortmann et al., 1998). Samples with uniform varieties samples are also preferred to mixtures, and beans are primarily marketed separately in Burundi, Rwanda, Zaire, Kenya , and Tanzania (Mishili et al., 2011; Wortmann et al., 1998). Tanzanian consumers also pay premiums for the variety Soya Kablanketi and demand discounts for any discolored grain (Mishili et al., 2011). Evidence from Rwanda also suggests that consumers do not place a premium on the chemical vs. non-chemical method in which are beans protected, but instead focus more on the quality of dry beans after storage (Dunkel et al., 1995).

Information about hedonic price formation is very important for all actors in the common bean value chain. Even where only 20% of common bean production is sold, farmers consider market preferences before choosing varieties to plant (Giga et al., 1992). Evidence from Mishili et al. (2011) demonstrates that bruchid-damaged beans are heavily discounted, at 2.3% per emergence hole in 100 bean grains. Therefore, in a 100 grain sample, the presence of 10 emergence holes could decrease the value of that sample by 23%.

Principal Storage Constraints

Short storage periods are historically prevalent among small bean producers, the largest component of the production chain (Giga et al., 1992). This is principally attributed to prohibitive storage damage from post-harvest insect infestation or cash-flow constraints (ibid). The most prominent and destructive of storage pests among common beans are the bruchid beetles *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) and *Zabrotes subfasciatus* (Boheman) (Coleoptera: Bruchidae), which cause average estimated dry weight losses of 10-40% (Kiula and Karel, 1985; Khamala, 1978). Dry weight losses of 50% and 70% have even been recorded where post-harvest management is especially poor (Lima, 1987; Khamala, 1978). Both storage pests cause grain damage in their larval stage by boring into the bean, where they seal themselves shut and feed until emerging as an adult (Songa and Rono, 1998). Holes resulting from their subsequent emergence are generally understood as "grain damage" (Mulungu et al., 2007; Songa and Rono, 1998). A farmer's inability to prevent heavy storage losses from insects may consistently force sales within 2-3 months, as they may incur "total crop loss" from insect infestation within 4-5 months (Giga et al., 1992). However, if a farmer in the Dar es Salaam area sold beans early after a May harvest to avoid insect damage, he would forfeit average potential price increases of 14.1% by December or even 17.5% by March. Producers in the sourcing regions for the Mbeya, Kigoma, and Songea markets may forfeit even higher seasonal price increases.

If credit is not available or interest rates are prohibitively high, farmers may sell early to pay post-harvest expenses. However, whole stores are rarely sold to meet immediate cash needs. When necessary, farmers tend to sell a portion of stocks and store the remainder "as long as possible" as a highly liquid asset. This asset has the potential to appreciate in value after harvest, peaking generally in the lean months before the following harvest, if maintained without damage. By selling early, the forfeited potential gain from commodity price increases over the marketing season may be interpreted as the "defacto" interest rate on liquidating these assets after harvest (Stephens and Barrett, 2009).

Methods for Controlling Bean Storage Pests

A. obtectus and *Z. subfasciatus* are often present together in storage infestations (Abate and Ampofo, 1996), but observations in Giga et al, (1992) indicate many circumstances of isolated infestation. *A. obtectus* is able to bore into un-threshed pods before harvest, while *Z. subfasciatus* is only able to infest once pods have been threshed for storage. In East Africa, timely harvest must be assured to avoid heavy field infestation by *A. obtectus* (Giga et al., 1992). If *A.obtectus* is present in the insect complex, bean stores are generally threshed "as soon as it is practical" and treated with protectants (ibid). Alternatively, stored beans are protected from *Z. subfasciatus* within un-threshed pods. Timing of threshing thus varies greatly on a regional basis, ranging from 1-4 days after drying when *A. obtectus* is present to two months after drying with isolated *Z. subfasciatus* infestations. Consequently, farmers must base storage strategies on both rainfall (moisture) conditions as well as the regional insect complex.

Solar disinfection of seeds between weighted plastic sheets has been demonstrated as an effective bruchid control technique in common bean (Songa and Rono, 1998) and cowpea legumes (Murdock and Shade, 1991). The solar disinfection method is generally promoted by extension agents, as well as the use of insecticides such as Actellic Super® (0.3% permethrin and 1.6% pirimiphos-methyl) (Songa and Rono, 1998). Results in Table 3 from Songa and Rono (1998) in Kenya show that corn oil, the solar disinfection method, and Actellic Super® performed comparably well in bruchid management during four months of storage. Solar disinfection is determined the most effective method on the basis that corn oil discolored grain and reduced market value (as verified by Mishili et al., 2011) and high insecticide residue may prove harmful for human consumption. Germination of seeds was also highest when treating with solar disinfection and Actellic Super®.

Table 3: Efficacy of Common Bean Storage Methods in Kenya after Four Months of Storage

Treatment	Percentage of Damaged Seeds	Appearance of Seed	Percentage of Seeds Germinated
Actellic Super®	0.9 ± 0.2	Unchanged	91.7 ± 4.2
Sunning & Sieving	0.7 ± 0.2	Unchanged	97.2 ± 2.8
Corn Oil	0.6 ± 0.1	Discolored	77.8 ± 6.5
Wood Ash	6.9 ± 3.0	Discolored	83.3 ± 7.2
Control	10.9 ± 4.6	Unchanged	77.8 ± 8.8

Source: Songa and Rono (1998)

Farmers may adopt a wide variety of traditional pest control methods, such as delaying threshing and admixing with ash, soil, inert dusts, plants oils and other botanicals (Cork et al., 2009). Botanical and plant material of varying protectant efficacy may include cypress, marigold, tagetes, and neem, among many others (Paul et al., 2009). However, extension agents generally discourage use of many botanical and "traditional" methods based on questionable efficacy (Songa and Rono, 1998), though botanical alternatives for bean storage are the focus of new scholarly attention (Paul et al., 2009; Mulungu et al., 2007; Paul, 2007). Paul et al. (2009) reports in Figure 4 that *A. indica* (neem) as a seed powder applied at 1.5kg/100kg beans maintains dry bean stores under 15% grain damage over a five month period, far surpassing other botanical leaf powder treatments in on-farm trials. Conversely, neem leaf powder applied at even 8.3 kg per 100kg of beans was unsuccessful as a protectant.

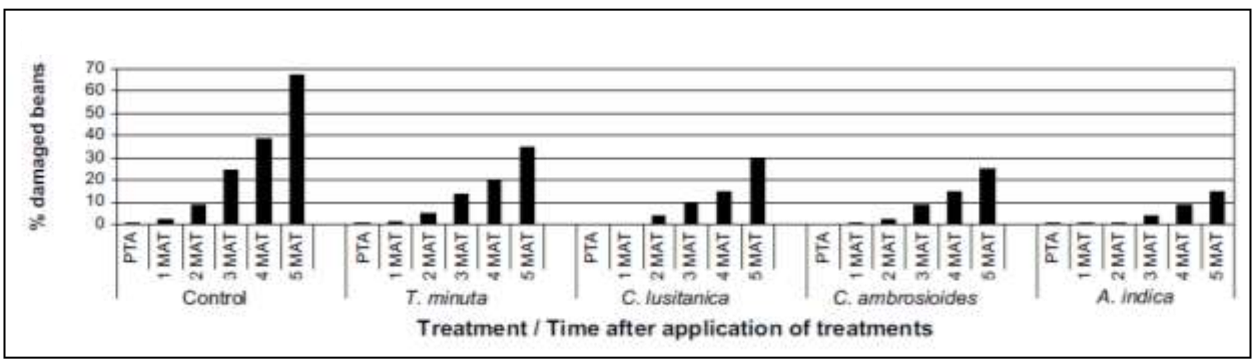

Figure 4: Percentage of Beans with Emergence Holes in Storage with Various Protectants
Source: Paul et al. (2009)

Other treatments receiving scholarly attention include utilization of diatomaceous earth (DE) products such as KeepDry®, a silica dioxide inert dust from fossilized rock. Laboratory experiments with DE products display a high *Z. subfaciatus* mortality rate at application rates of 0.75g/kg and 1.00g/kg (Lazzari and Ribeiro-Costa, 2006). Intertemporal dry weight loss and bean damage estimates were unfortunately not presented in this study, making it impossible to compare efficacy with storage treatments.

Researchers have also developed seeds with varietal resistance from areclin, a lectin, which offers strong resistance to *Z. subfasciatus* but little protection from *A. obtectus* (Cork et al., 2009; Velten et al., 2007; Kusolwa, 2007; Mamo, 2010). Results for this hybrid are considered promising and beans with this genetic resistance have been manufactured, yet few farmers have received improved varieties to date (Cork et al., 2009).

Effects on Germination

Farmers in Eastern Africa are generally aware of the need for clean, undamaged seed for maximum germination (Giga et al., 1992). Baier and Webster (1992) and Songa and Rono (1998) confirm general knowledge that bruchid damage from emergence holes negatively impacts seed germination. Extension recommendations also caution against long sessions of solar disinfection, as sessions lasting for one or more hours can result in 0% - 35% germination rates (Agona and Nahdy, 1998).

Purdue Improved Cowpea Storage (PICS) bags

Triple-layer hermetic Purdue Improved Crop Storage (PICS) bags were developed under the Bean/Cowpea CRSP project in the late 1980s through funding from USAID (Murdock et al., 2003). Hermetic technology works by creating an airtight seal in which oxygen levels dramatically decrease within days through insect, fungal, and/or seed respiration (Quezada et al., 2006). The high density polyethylene PICS 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 (Baributsa et al., 2010). This technology was originally created until the trademark "Purdue Improved Cowpea Storage (PICS) for West and Central African cowpea farmers to protect against extremely destructive cowpea bruchids, which prevented resource-constrained farmers from long-term storage to capture price increases later in the marketing season. Moussa (2006) conducted an impact assessment of the Bean/Cowpeas CRSP project and estimates that, due to the introduction of hermetic technology in the region, over 500,000 additional tons of cowpea are now conserved per year, resulting in $100 million USD in *annual* additional cowpea income.

The success of PICS bags with cowpeas has induced producers and researchers alike to begin experimentation with storage of other commodities. To date, PICS bags have displayed 50% lower cassava chip storage losses compared to conventional polypropylene bags over a two month period (Ognakossan et al. 2010). Research by Ognakossan et al. is still in progress at the time of this analysis and will yield more long-term results soon. Hell et al. (2010) also displayed that PICS bags can provide extremely high rates of protection for maize grain, remaining under 0.5% dry weight loss after a six month period. While no direct studies have thus far been conducted with PICS bags for common bean storage, field experiences allow for estimations (based on cowpea losses) of about 0.6% dry weight loss in long-term storage.

Key Literature Review Conclusions

1) Dry beans are of significant nutritional and economic importance in many regions of Eastern and Southern Africa (Giga et al., 1992; Wortmann et al., 1998; FAO STAT, 2010).

2) Stored beans are consumed by the household, stored for seed, or marketed at a later date (Wortmann et al., 1998; Giga et al., 1992).

3) Average seasonal price increases from post-harvest months to the annual high-price month are estimated between 17.4% - 58.7% in Tanzania, 16.8% - 33.5% in Kenya, and 31.2% – 100.0% in Uganda (FEWS NET, 2010b,c,d).

4) Among other consumer preferences, emergence holes from storage pests *Z. subfaciatus* and *A. obtectus* result in significant quantified price discounts in bean grain samples (Mishili et al., 2011).

5) Many extension offices promote pests control strategies as insecticide use and/or solar disinfection (Songa and Rono, 1998), though certain botanicals show potential as storage treatments (Paul et al., 2009).

6) PICS hermetic storage bags may provide a new alternative for long-term storage of common beans with minimal grain damage or dry weight losses, based on results with other commodities (Murdock et al., 2003; Hell et al., 2010; Ognakossan et al., 2010).

Data

In this meta-analysis, returns from storage will be calculated for bean storage utilizing PICS bags, Actellic Super® insecticide treatments, solar disinfection, or the botanicals for which Paul et al., (2009) conduct their extended period loss analysis. Conclusions are then drawn to determine the cost-effectiveness of PICS bags within this range of current storage technology options. As the United Republic of Tanzania represents the largest national common bean producer in Africa, this country was selected for in-depth analysis in diverse market scenarios.

Price Data

Market price data for Tanzania was accessed through the recent Famine Early Warning System (FEWS) price bulletins, which are recorded as charts of nominal five-year monthly wholesale averages (September 2006 – September 2010). Experience with maize price data shows that five-year monthly averages can result in two months appearing as the global low and high price periods, when actual individual annual high and low price months may be occur without a distinct pattern (Chapoto and Jayne, 2010). In the case of Tanzanian common beans, the five-year averaged low and high price months match other qualitative literature on the general peak of the lean season (June) and the general major harvest month (October) (WFP 2010; WFP 2009). Experience with richer data sets also shows that disparities between high and low price months in five-year averaged data may be dramatically lower than actual annual disparities (Chapoto and Jayne, 2010). Therefore, the nominal averages were determined to be a conservative measuring tool to gauge the potential profitability for PICS bags, and thus appropriate in this analysis. The data thus appear to be a smoothed trend with the actual high and low price months correctly identified by the averages, serving as a conservative estimation of potential storage gains.

As numerical data could not be retrieved in the evaluated countries for the entire five-year period, the FEWS NET data, with graphical representations of average monthly prices, provided the best insight on price trends. To extract numerical data, the graphics were first copied from the price bulletins into Microsoft Word®, then cropped and enlarged to focus on price intervals. This image was then super-imposed on a respective table which was spaced evenly throughout the intervals to replicate minor gridlines. Thus, prices could be estimated from the charts with reasonable, yet imperfect accuracy (estimated range of error 1-2%).

Farm-gate prices are then assumed to conservatively represent 75% of wholesale prices, based on data from a 2009 MSU/Tegemeo University maize market chain study in Kenya including 534 households, 46 small traders, and 36 medium-scale wholesalers (Kirimi et al., 2010). All marketing margins are assumed to remain constant throughout the year. Further, farmers are assumed to be able to sell beans at any month desired.

Treatment Data

Losses from common bean bruchids in storage with PICS bags are still under active laboratory and field investigation. The similarity of common bean and cowpea bruchids merited this accelerated economic evaluation, and losses are assumed to be comparable with hermetic cowpea storage (Boys et al., 2007). The only insecticide for which documented inter-temporal damage estimates were provided was Actellic Super (permethrin (0.3%) + pirimiphos-methyl (1.6%)) (Songa and Rono, 1998). Songa and Rono (1998) also provide the only common bean research with inter-temporal damage estimates for the solar disinfection and sieving (S&S) technique. Grain damage estimates are also documented in field studies utilizing cypress, marigold, tagetes, and neem (Paul et al., 2009). Thus, these pest-control strategies are used for economic comparison with PICS bags. However, grain damage data is only reported for four months of storage by Songa and Rono (1998) and up to five months of storage by Paul et al. (2009). Price maximum months in Tanzanian study markets occurred six or more months after the assumed harvest month. To be conservative, damage levels with treatments from Songa and Rono (1998) and Paul et al., (2009) are always considered at four month levels, even if the optimal storage period is longer. As controls from each study showed remarkably varied rates of grain damage at four months of storage, the damage levels from the northern Tanzanian study (Paul et al., 2009) will be scaled to the more conservative Kenyan study zone (Songa and Rono, 1998) as a percentage of treatment vs. control losses. Grain damaged is also defined as the percentage of beans with emergence holes. Mishili et al. (2009) describe quality discounts for each emergence hole per 100 seeds, but, under constrained information, this analysis will conservatively assume only one hole per seed is present in a “damaged” grain.

Both dry weight losses and the percentage of grains damage are important in calculating revenues of stored beans. The field studies available, however, only documented the percentage of grain damage at the noted time periods. A laboratory experiment, conducted by Mulungu et al. (2007) provides a limited range of results documenting both dry weight losses and corresponding grain damage levels. Figure 5 displays the relationship between these two variables and resulting predictive linear equation. This linear relationship is utilized to conservatively link the two variables and estimate corresponding levels of dry weight loss in storage treatment data from Songa and Rono (1998) and Paul et al. (2009). Holst et al. (2000) derived comprehensive equations relating dry weight losses and grain damage in maize grain, showing the relationship to be exponential. Thus, the limited linear equation for beans in Figure 5 is only meant to provide a conservative estimate of losses beyond the data range of Mulungu et al. (2007). It is important to note that all grain damage data from Songa and Rono (1998) and Paul et al. (2009) at four months of storage fell within the documented range. Only loss estimates for bean storage without treatment exceeded the data range from Mulungu et al. (2007).

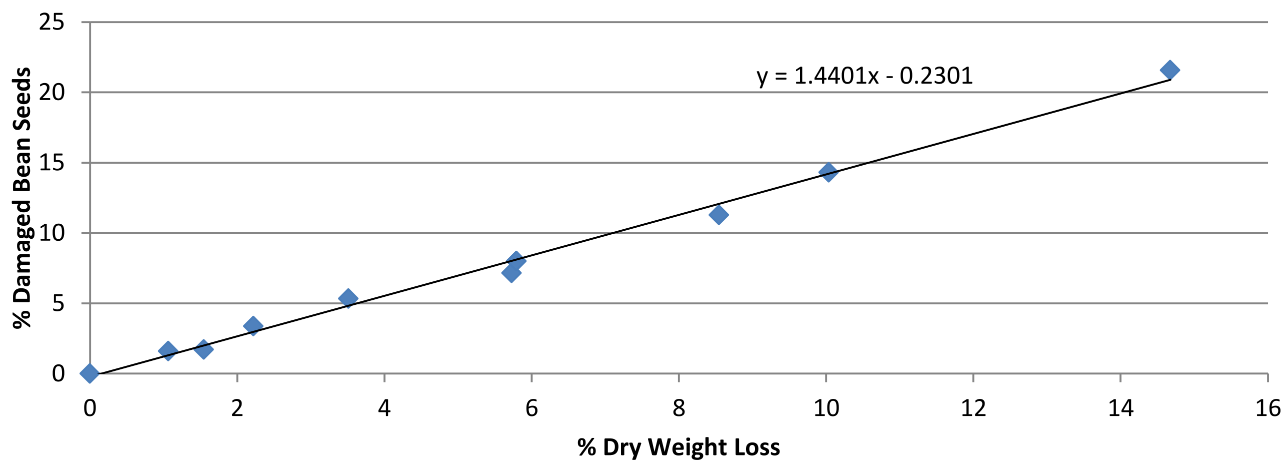

Figure 5: Relationship between damaged bean seeds to dry weight loss levels
Source: Mulungu et al. (2007)

<u>Cost Data</u>

Costs of insecticides and polypropylene bags for non-PICS storage are based on recent field experience in Ghana. As price data for these items were not available from Tanzania, costs are assumed to be equal to that in Ghana. Botanicals are assumed to be locally available, requiring only labor as a search cost. This personal labor cost is conservatively assumed to be zero for this analysis. Labor costs for the weekly solar disinfection and sieving of beans are also considered zero, though Songa and Rono (1998) report that many producers complain of the laborious difficulty of weekly treatments.

Study Area

Previous nationwide bean bruchid studies in Tanzania have identified nine major bean growing regions in Tanzania: Tanga, Kilimanjaro, Arusha, Bukoba, Mwanza, Morogoro, Mbeya, and Ruvuma, and Kigoma (Nchimi-Msolla and Misangu, 2002). Figure 6 from FEWS NET verifies current production and trade patterns dominated from these regions in 2010. Available price data from FEWS bulletins, however, only reported data for markets in Dar es Salaam, Dodoma, Mbeya, Arusha, Kigoma, and Songea [Ruvuma region]. Therefore, this producer-focused study will report results only from the four major markets in production regions, excluding the Dar es Salaam and Dodoma markets.

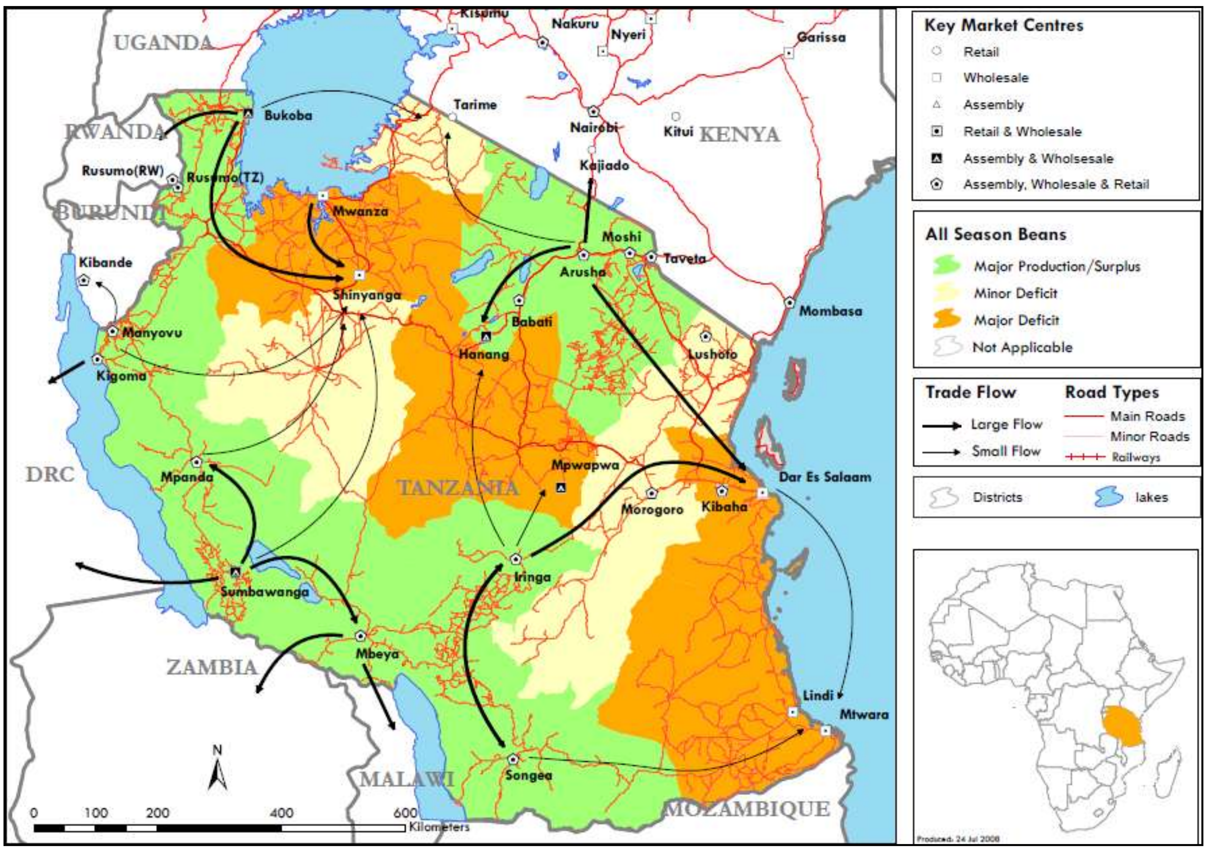

Figure 6: Bean Production Regions and Trade Patterns, 2010
Source: FEWS NET (2010)

Methodology

Calculating Returns on Storage

Returns for storage were evaluated in comparison to the benchmark of marketing immediately after harvest vs. always selling six months after harvest and/or at the month with the maximum price in the common bean marketing season. Harvest periods were determined by FEWS data and verified by planting and harvesting planning descriptions in from CRSP workshop reports

(Nchimbi-Msolla and Misangu, 2002). Returns to storage in marketing regions throughout Tanzania were calculated from the five-year nominal averages under varying opportunity costs to represent a larger spectrum of the potential adopting producers.

From the small-producer's benchmark option to sell directly after harvest, returns on storage were calculated with the best estimation from the literature of expected losses with each storage technology for each storage period. For sensitivity analysis, returns to storage are also calculated for 5% above and below the expected losses from control samples (no storage technology).

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. The cost of the PICS bag was straight-line depreciated over two years, and returns on storage presented as an average of year one and two. As production costs vary greatly across the country, these parameters were not included in the model. Caution should therefore be exercised, as Nominal Crop Income refers to crop revenue, net storage costs.

Results

Tables 4 and 5 document the process by which returns on storage are derived for each technology in the various market regions. This example is from the Mbeya region for producers with an opportunity cost of capital (OCC) of 25%, the lowest possible OCC examined in this analysis. Under these conditions, meant to rigorously test PICS bags against current treatments, the hierarchy of treatments with respect to potential returns of storage is:

1) Solar disinfection and sieving (S&S),
2) PICS bags utilized for two years,
3) Actellic Super,
4) PICS bags utilized for only one year,
5) *A. Indica*,
6) *C. Ambrosioides*,
7) *C. Lusitanica*, and
8) *T. Minuta*

Based on fixed loss estimates and costs for each treatment, this order will remain constant throughout all markets examined. Market regions vary in magnitude of price fluctuations and this analysis will provide a method to measure the profitability of treatments. Further sensitivity analysis follows the results section, which utilizes alternate loss estimates for non-PICS technology based on control losses in Songa and Rono (1998).

Table 4: Derivation of Revenues for Producers in Mbeya (25% OCC)

	Sell Beans at Harvest	Common Bean Storage Technology Options					
		PICS Bags		S&S	Actellic Super	Botanicals[1]	
		One Year Use	Two Years of Use (Avg)			*A. Indica*	*C. Ambrosioides*
Selling Period:	June	December					
Sample Production (kg)	100	100	100	100	100	100	100
Dry Weight Loss (%)	-	0.60	0.60	0.65	0.78	1.87	3.04
Beans Marketed (kg)	**100**	**99.40**	**99.40**	**99.35**	**99.22**	**98.13**	**96.96**
Beans Damaged[2] (%)	-	0.63	0.63	0.70	0.90	2.46	4.15
Farm-gate Price (1000 TZS/kg)	0.43	0.60	0.60	0.60	0.60	0.60	0.60
Price Received with Damage Discount[3]	**0.43**	**0.591**	**0.591**	**0.590**	**0.588**	**0.566**	**0.543**
Total Revenue (1000 TZS)	**43.13**	**58.77**	**58.77**	**58.65**	**58.30**	**55.55**	**55.62**

[1] The botanicals *C. Lusitanica* and *T. Minuta* were also analyzed in subsequent sections, but excluded in this example

[2] Interpreted as the percentage of beans with emergence holes present

[3] Discount of 2.3% applied for each percentage of beans damaged (by definition in footnote 3)(Mishili et al., 2011). Discounted Price = (FG Price) – (0.023)(% Beans Damaged)(FG Price)

Table 5: Derivation of Storage Costs and Returns on Storage for Producers in Mbeya (25% OCC)

	Sell Beans at Harvest	Common Bean Storage Technology Options					
		PICS Bags		S&S	Actellic Super	Botanicals	
		One Year Use	Two Years of Use (Avg)			*A. Indica*	*C. Ambrosioides*
Selling Period:	June	December					
Total Revenue	**43.13**	**58.77**	**58.77**	**58.65**	**58.30**	**55.55**	**55.62**
Storage Costs							
Sieve Cost[4] (1000 TZS)	-	-	-	0.36	-	-	-
Insecticide Cost (1000 TZS)	-	-	-	-	0.99	-	-
Storage Bag Costs (1000 TZS)	-	2.86	1.43	0.49	0.49	0.49	0.49
Total Storage Costs	**-**	**2.86**	**1.43**	**0.85**	**1.48**	**0.49**	**0.49**
Nominal Total Crop Income	**43.13**	**55.91**	**57.34**	**57.80**	**56.82**	**55.05**	**52.13**
Opportunity Cost of Capital (25%) (1000 TZS)	-	5.75	5.57	5.50	5.58	5.45	5.45
Gain from Storage	**-**	**7.04**	**8.65**	**9.18**	**8.12**	**6.47**	**3.55**
Percent Gain on Investment	**-**	**15.30%**	**19.40%**	**21.11%**	**18.40%**	**15.01%**	**8.24%**

[4] Derived from Songa and Rono (1998). Straight-line depreciated from stated 10-year lifespan.

Mbeya market region

Table 6 displays monthly wholesale data extracted from FEWS NET charts. Farm-gate prices in Table 6 represent 75% of wholesale prices, following Kirimi et al. (2010). Figure 7 shows that nominal prices display much less seasonality in 2009 and 2010 than in the 39.2% June-December increase in the 2005-2008 period. This underscores the fact that storing beans will inevitably vary in profitability from year to year.

Table 6: Extracted Wholesale and Farm-gate Bean Prices in Mbeya

Extracted Nominal Five-Year Average Wholesale Prices in Mbeya (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
575	631	638	663	700	731	800	710	730	695	640	650
Derived Farm-gate Prices (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
431	473	478	497	525	548	600	533	548	521	480	488

Source: Extracted from FEWS NET chart in Figure 7; Farm-gate discounting factor (75% of wholesale price) from Kirimi et al. (2010)

Figure 7: FEWS NET Chart of Nominal Wholesale Bean Prices in Mbeya, Tanzania
Source: FEWS NET (2010)

Results in Table 7 conservatively estimate that all modeled treatments could provide positive storage returns for producers when evaluated at a 25% OCC. Actellic Super, solar disinfection and sieving (S&S), *A. indica* (neem), and PICS bags, in particular,could provide economic returns to storage from 15.3 – 22.4%. Even producers with opportunity costs of capital of 55% would attain some positive returns to storage, indicating storage protection could be a beneficial investment for a wide range of potential adopters.

Table 7: Returns on Storage (%) in Mbeya under Various Opportunity Costs of Capital.

OCC	No Treatment (DWL Levels)			Botanical Treatments				Extension Promoted Treatments		PICS Bags	
	30%	20%	10%	*T. Minuta*	*C. Lusi-tanica*	*C. Ambro-sioides*	*A. Indica*	Actellic Super	S&S	One Year Use	Two Years (Avg)
25%	(112.7)	(75.6)	(29.4)	2.4	8.0	8.2	15.0	18.4	21.1	15.3	19.4
35%	(117.7)	(80.7)	(34.4)	(2.6)	2.9	3.2	10.0	13.3	16.1	10.3	14.4
45%	(122.8)	(85.7)	(39.5)	(7.7)	(2.2)	(1.9)	4.9	8.3	11.0	5.3	9.4
55%	(127.8)	(90.8)	(44.6)	(12.8)	(7.2)	(6.9)	(0.2)	3.2	5.9	0.3	4.4

Note: Losses from Paul et al. (2009) scaled to the four month control for Songa and Rono (1998)
DWL- Dry weight loss

<u>Songea</u>

Table 8 illustrates that the Songea market experiences the lowest average price in June and highest peak in December. However, Figure 8 displays that prices in 2009 and 2010 peak in January and February followed by troughs in March and April. This seasonality pattern is logical in a unimodal zone (single rainfall period), but it is not known how annual patterns behaved in previous years for comparison. The Songea market displays the second highest average seasonal price increases in Tanzania, rising 46.1% from June to December.

Table 8: Extracted Wholesale and Farm-gate Bean Prices in Songea, Tanzania

Derived Nominal Five-Year Average Wholesale Prices in Songea (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
445	452	449	500	553	572	650	650	644	469	469	493
Derived Nominal Five-Year Average Farm-gate Prices in Songea (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
334	339	337	375	415	429	488	488	483	352	352	370

Source: Extracted from FEWS NET chart in Figure 8; Farm-gate discounting factor from Kirimi et al. (2010)

Figure 8: FEWS NET Chart of Nominal Wholesale Bean Prices in Songea, Tanzania
Source: FEWS NET (2010)

Due to greater seasonal price fluctuations, higher returns to storage may be possible in the Songea region. The botanicals *C. Lusitanica* and *C. Ambrosioides* now also show potential for returns over 10% for producers with low opportunity costs of capital. Utilization of PICS bags for two years, Actellic Super, *A. indica*, and the S&S technique provide potential returns over 20%. For these treatments, even producers with the highest modeled opportunity costs would attain positive returns to storage.

Table 9: Returns on Storage (%) in Songea under Various Opportunity Costs of Capital.

OCC	No Treatment (DWL Levels)			Botanical Treatments				Extension Promoted Treatments		PICS Bags	
	30%	20%	10%	T. Minuta	C. Lusi-tanica	C. Ambro-sioides	A. Indica	Actellic Super	S&S	One Year Use	Two Years (Avg)
25%	(116.6)	(74.1)	(25.6)	7.8	13.7	13.9	21.1	23.7	27.1	19.3	24.7
35%	(123.2)	(79.2)	(30.6)	2.8	8.6	8.9	16.0	18.7	22.1	14.3	19.7
45%	(129.7)	(84.2)	(35.7)	(2.3)	3.5	3.8	10.9	13.6	17.0	9.3	14.7
55%	(136.2)	(89.3)	(40.8)	(7.4)	(1.6)	(1.3)	5.8	8.5	11.9	4.3	9.7

Note: Losses from Paul et al. (2009) scaled to the four month control for Songa and Rono (1998); DWL- Dry weight loss

Kigoma

Table 10 displays average monthly wholesale price data from Kigoma, similarly peaking in the month of December. Figure 9 shows that nominal prices in 2009 display price seasonality that closely matches the five-year averages, though 2010 prices demonstrate considerable volatility. The Kigoma market experiences the highest average price increases of all Tanzanian markets studied, rising 59% from June to December.

Table 10: Extracted Wholesale and Farm-gate Bean Prices in Kigoma, Tanzania

Extracted Nominal Five-Year Average Wholesale Prices in Kigoma (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
650	690	738	819	888	969	1031	914	827	763	750	750
Derived Farm-gate Prices in Kigoma (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
488	518	553	614	666	727	773	686	620	572	563	563

Source: Extracted from FEWS NET chart in Figure 9; Farm-gate discounting factor from Kirimi et al. (2010)

Figure 9: Nominal Wholesale Bean Prices in Kigoma, Tanzania
Source: FEWS NET (2010)

Potential returns on storage in Kigoma are the highest of all examined Tanzanian sourcing regions. PICS bags utilized for one or two years yield potential economic returns of 34.3% and 38.5%, respectively at 25% OCC. Botanical treatments all show positive returns on storage, ranging from 18.9 – 33.2%. Continuing the assumption of zero labor costs, the solar disinfection and sieving treatment could reach economic returns over 40%.

Table 11: Returns on Storage (%) in Kigoma under Various Opportunity Costs of Capital.

OCC	No Treatment (DWL Levels)			Botanical Treatments				Extension Promoted Treatments		PICS Bags	
	30%	20%	10%	T. Minuta	C. Lusi-tanica	C. Ambro-sioides	A. Indica	Actellic Super	S&S	One Year Use	Two Years (Avg)
25%	(110.9)	(70.1)	(17.4)	18.9	25.2	25.5	33.2	37.5	40.3	34.3	38.5
35%	(115.4)	(75.2)	(22.4)	13.8	20.1	20.5	28.2	32.4	35.3	29.3	33.5
45%	(119.9)	(80.2)	(27.5)	8.8	15.1	15.4	23.1	27.4	30.2	24.3	28.5
55%	(124.3)	(85.3)	(32.5)	3.7	10.0	10.4	18.1	22.3	25.2	19.3	23.5

Note: Losses from Paul et al. (2009) scaled to the four month control for Songa and Rono (1998)

Arusha

Arusha is located in the bimodal rainfall zone, contributing to the market region's lower seasonal price variation. This market zone has the lowest global high/low price increases in the Tanzanian, rising only 17% from June to March. The first local price maximum in November is only 7.2% higher than harvest month prices. Returns on storage were calculated using sale at both local and global maximum price months.

Table 12: Extracted Wholesale and Farm-gate Bean Prices in Arusha, Tanzania

Derived Nominal Five-Year Average Wholesale Prices in Arusha (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
700	713	719	731	740	750	740	755	781	822	800	760
Derived Nominal Five-Year Average Farm-gate Prices in Arusha (TZS/kg)											
June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
525	534	539	548	555	563	555	566	586	617	600	570

Source: Extracted from FEWS NET chart in Figure 10

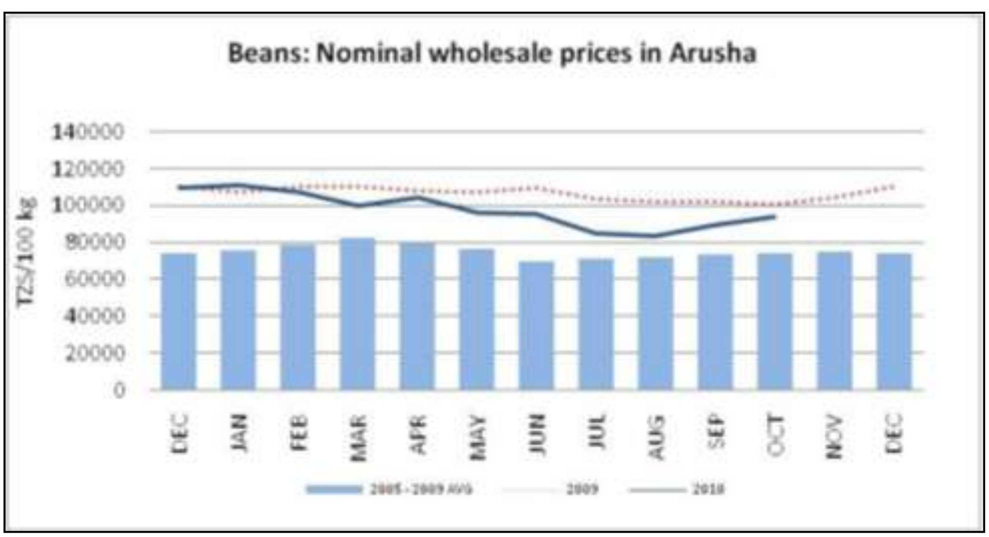

Figure 10: FEWS NET Chart of Nominal Wholesale Bean Prices in Arusha, Tanzania
Source: FEWS NET (2010)

Tables 13 and 14 display that positive returns to storage would not be realized by Arusha-region producers targeting the first or annual price maximums. Even though the price appreciates an additional 9.6% from November to March, the opportunity cost of holding this capital is primarily responsible for the erosion of potential returns. This may help to explain why producers sell early, as even perfect grain protection may not be beneficial for a market-oriented producer. This model suggests that profit-maximizing producers in the Arusha region should thus sell common bean stocks at harvest and invest the bean revenue in endeavors providing higher returns.

Table 13: Returns on Storage (%) in Arusha for five months of storage under various Opportunity Costs of Capital.

	No Treatment (DWL Levels)			Botanical Treatments				Extension Promoted Treatments		PICS Bags	
OCC	30%	20%	10%	T. Minuta	C. Lusi-tanica	C. Ambro-sioides	A. Indica	Actellic Super	S&S	One Year Use	Two Years (Avg)
25%	(109.6)	(81.3)	(46.0)	(21.8)	(17.5)	(17.3)	(12.2)	(9.2)	(7.4)	(10.9)	(8.3)
35%	(113.7)	(85.5)	(50.2)	(25.9)	(21.7)	(21.5)	(16.3)	(13.3)	(11.5)	(15.1)	(12.4)
45%	(117.9)	(89.6)	(54.4)	(30.1)	(25.9)	(25.7)	(20.5)	(17.5)	(15.7)	(19.2)	(16.6)
55%	(122.1)	(93.8)	(58.5)	(34.3)	(30.0)	(29.8)	(24.7)	(21.7)	(19.9)	(23.4)	(20.8)

Note: Losses from Paul et al. (2009) scaled to the four month control for Songa and Rono (1998)
DWL- Dry weight loss

Table 14: Returns on Storage (%) in Arusha for nine months of storage under various Opportunity Costs of Capital.

	No Treatment (DWL Levels)			Botanical Treatments				Extension Promoted Treatments		PICS Bags	
OCC	30%	20%	10%	T. Minuta	C. Lusi-tanica	C. Ambro-sioides	A. Indica	Actelli c Super	S&S	One Year Use	Two Years (Avg)
25%	(117.8)	(86.8)	(48.2)	(21.6)	(17.0)	(16.7)	(11.1)	(7.8)	(5.8)	(9.7)	(6.8)
35%	(125.3)	(94.3)	(55.7)	(29.1)	(24.5)	(24.2)	(18.6)	(15.3)	(13.3)	(17.2)	(14.3)
45%	(132.8)	(101.8)	(63.2)	(36.6)	(32.0)	(31.7)	(26.1)	(22.8)	(20.8)	(24.7)	(21.8)
55%	(140.3)	(109.3)	(70.7)	(44.1)	(39.5)	(39.2)	(33.6)	(30.3)	(28.3)	(32.2)	(29.3)

Note: Losses from Paul et al. (2009) scaled to the four month control for Songa and Rono (1998)
DWL- Dry weight loss

Sensitivity Analysis

PICS bags were compared to other current storage treatments according to their most conservative (i.e. lowest) inter-temporal loss figures in the literature. Further sensitivity analysis is conducted to scale bean grain damage results for insecticide and solar disinfection treatments from Songa and Rono (1998) to the much higher four-month control in Paul et al. (2009). In this scenario, one and two year use of PICS bags become the most profitable options, and use of botanicals for storage protection becomes almost universally unprofitable[5]. Continuing the assumption of zero labor costs for solar disinfection and sieving, this storage option retains higher returns on storage than Actellic Super. It is very important, therefore, to consider the environment context in which analysis is conducted for the most appropriate assessment of the benefit of technology transfer.

Table 15: Return on Storage Frontier when Scaling Loss Estimates to Paul et al. (2009)

OCC		No Treatment (DWL Levels)			Botanical Treatments				Extension Promoted Treatments		PICS Bags	
		30%	20%	10%	T. Minuta	C. Lusi-tanica	C. Ambro-sioides	A. Indica	Actellic Super	S&S	One Year Use	Two Years (Avg)
Mbeya	25%	(112.7)	(75.6)	(29.4)	(49.2)	(32.3)	(31.4)	(9.6)	9.2	13.9	15.3	19.4
	55%	(127.8)	(90.8)	(44.6)	(64.4)	(47.5)	(46.6)	(24.8)	(5.9)	(1.3)	0.3	4.4
Songea	25%	(116.6)	(74.1)	(25.6)	(46.4)	(28.6)	(27.7)	(4.8)	14.2	19.5	19.3	24.7
	55%	(136.2)	(89.3)	(40.8)	(61.6)	(43.8)	(42.9)	(20.0)	(1.0)	4.3	4.3	9.7
Kigoma	25%	(110.9)	(70.1)	(17.4)	(40.0)	(20.7)	(19.7)	5.2	27.0	32.1	34.3	38.5
	55%	(124.3)	(85.3)	(32.5)	(55.2)	(35.9)	(34.9)	(10.0)	11.9	16.9	19.3	23.5
Arusha (5 mo)	25%	(109.6)	(81.3)	(46.0)	(61.2)	(48.2)	(47.6)	(30.9)	(16.2)	(12.9)	(10.2)	(8.3)
	55%	(122.1)	(93.8)	(58.5)	(73.7)	(60.7)	(60.1)	(43.4)	(28.7)	(25.4)	(23.7)	(20.8)
Arusha (9 mo)	25%	(117.8)	(86.8)	(48.2)	(64.8)	(50.6)	(49.9)	(31.6)	(15.5)	(11.9)	(9.7)	(6.8)
	55%	(140.3)	(109.3)	(70.7)	(87.3)	(73.1)	(72.4)	(54.1)	(38.0)	(34.4)	(17.2)	(29.3)

[5] Note: Data from botanicals as storage protectants taken originally from Paul et al. (2009).

Conclusions

Substantial pest damage is associated with common bean storage in Eastern Africa. Evidence from market studies suggests that financial losses for producers occur not only in the form of dry weight losses, but also compound with quality discounts for damaged beans. Consideration of these compounding factors is crucial when evaluating total value loss and thus the benefit of technologies preventing this damage in medium to long-term storage. For producers to capture the greatest benefits from price seasonality in most Tanzanian market regions, long-term storage of approximately six months is required. The market regions of Mbeya, Songea, and Kigoma offer a price incentive for investment in long-term bean storage technology, while the Arusha market offers substantially less incentive.

Under reasonable and conservative assumptions, this analysis demonstrates that PICS bags have the potential to provide substantial returns to storage for marketing producers in most marketing regions within Tanzania. With the most conservative (i.e. lowest) loss estimates in the literature for alternative technologies (Songa and Rono, 1998), PICS bags do not provide the highest returns to storage, but are competitive. Further, PICS bags do provide the highest return, whether used for one or two years, when losses are scaled to higher estimates in Paul et al. (2009).

The advantages of PICS storage technology will be most beneficial in regions where *A. obstectus* and *Z. subfasciatus* bruchid infestation is high and seasonal market price fluctuations are substantial. Investigations into regional common bean hedonic price formation, incorporating quality discounts for damaged bean grains, will also provide additional insight into the zones of highest potential benefit. Examination of the implications of regional producers' marketing rates may also help identify zones of greatest potential impact.

Several key assumptions will need further investigation to test for robustness of results. The assumption of zero labor costs for weekly solar disinfection contributes greatly to its estimated high returns to storage. This should be a topic of further investigation, as producers may be unwilling to spend the time necessary conducting the treatment. PICS technology requires minimal labor only at the time of filling and emptying the triple-layer sacs, and could provide a more enticing and competitive storage option for producers with higher personal labor costs. The product's nature as a durable good also provides an advantage over one-time use of insecticides and botanical alternatives. Additionally, the absence of pesticide requirements with PICS storage technology may add value for producers (and consumers) that is not adequately captured in this model. Acquisition of more robust inter-temporal price data will also provide considerably greater capacity for market analysis, including study of annual variances in returns to storage and a subsequent risk analysis for investing producers.

References

Abate, T. and J.K.O. Ampofo (1996). Insect pests of beans in Africa: their ecology and management. *Annual Review of Entomology*. 41: 45-73.

Agona, J.A. and S.M. Nahdy (1998). Effect of Solar Drying Period of Beans on Seed Viability, Cooking Time, and Injuriousness of *Acanthoscelides Obtectus* Say. *African Crop Science Journal.* 6(4): 417-421.

Baier, A.H. and B.D. Webster (1992). Control of *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae) in *Phaseolus vulgrais* L. seed stored on small farms- II. Germination and cooking time. *Journal of Stored Products Research.* 28(4): 295-299.

Bartibutsa, D., J. Lowenberg-DeBoer, L. Murdock, and B. Moussa (2010). Profitable chemical-free cowpea storage technology for smallholder farmers in Africa: opportunities and challenges. *10th International Working Conference on Stored Product Protection.* Pp. 1046-1052

Boys, K., M. Faye, J. Fulton and J. Lowenberg-DeBoer (2007). The impact of cowpea research in Senegal: an ex-post analysis with disadoption. *Agricultural Economics* (36): 363–375

Dunkel, F.V., A. Sergugendo, W.M. Breene, and S. Sriharan (1995). Influence of insecticidal plant amterials used during storage on sensory attributes and instrumental hardness of dry edible beans (*Phaseolus vulgaris* L.). *Plant Foods for Human Nutrition.* 48: 1-16.

FAOSTAT (2010), FAOSTAT Database, Purdue University.

FAO TradeSTAT (2010), FAO TradeSTAT Database, Purdue University

FEWS NET (2010a).Seasonal Calender and Critical Events Timeline, Tanzania 2010-2011. http://v4.fews.net/pages/timelineview.aspx?gb=tz&tln=en&l=en. 23 November, 2010.

FEWS NET (2010b). Tanzania Monthly Price Bulletin, September 2010. Famine Early Warning Systems Network (FEWS NET).

FEWS NET (2010c). Kenya Monthly Price Bulletin, October 2010. Famine Early Warning Systems Network (FEWS NET).

FEWS NET (2010d). Uganda Monthly Price Bulletin, September 2010. Famine Early Warning Systems Network (FEWS NET).

Hell, K., K.E. Ognakossan, A.K. Tonou, Y. Lamboni, K.E. Adabe, and O. Coulibaly (2010). Maize Stored Pests Control by PICS-Bags: Technological and Economic Evaluation. Presentation at the 5th World Cowpea Conference, Saly, Senegal, 27 September – 1 October 2010.

Hillocks, R.J., C.S. Madata, R. Chirwa, E.M. Minja, and S. Msolla (2006). Phaseolus Bean Improvement in Tanzania, 1959-2005, Euphytica (2006), Springer.

Holst, N., Meikle, W.G., and Markham, R.H. (2000). Grain Injury Models for *Prostephanus truncates* (Coleoptera: Bostrichidae) and *Sitophilus zeamis* (Coleoptera: Curculionidae) in Rural Maize Stores in West Africa. *Journal of Economic Entomology*. 93(4): 1338-1346

Jones, A.L. (1999). Chapter IV. Phaseolus Bean: Post-Harvest Operations. *Compendium on Post-Harvest Operations.* Mejia, D., Lewis, B., and Bothe, C., eds. FAO, Rome, Italy.

Khamala, C.P.M. (1978). Pests of grain legumes and their control in Kenya. Within R. Singh, H.F. Van Emolen and T.A. Taylor, (eds). *Pests of Grain Legumes: Ecology and Control* (London: Academic Press). pp. 127-134

Kiula, B.A. and A.K. Karel (1985). Effectiveness of vegetable oils in protecting beans against Mexican bean weevil (*Z. subfasciatus*). *Annual Report to the Bean Improvement Cooperation, vol. 28.* Bean Improvement Cooperative, Geneva. pp. 3-5.

Kirimi, L., N. Sitko, T.S. Jayne, F. Karin, M. Muyanga, M. Sheahan, J. Flock, and G. Bor (2010). Kenya's Maize Value Chain: Toward Strategic Interventions to Address National Policy Challenges. *Tegemeo Institute of Agricultural Policy and Development Conference.* Karen, Nairobi, 27 October, 2010.

Kusolwa, P.M. (2007). Breeding for Bruchid Resistance in Common Bean (*Phaseolus vulgaris* L.) Interspecific Introgresson of Lectin-like Seed Proteins from Tepary Bean (*P. acutifolius* A. Gray), Genetic Control and Bruchid Resistance Characterization. *Dissertation for Doctor of Philosophy in Horticulture*, Oregon State University. Corvallis, Oregon, United States of America.

Lazzari, F.N., Ribeiro-Costa, C.S. (2006). Control of *Zabrotes subfasciatus* (Boheman) (Coleoptera, Chrysomelidae,Bruchinae) in *Phaseolus vulgaris* Linnaeus, using diatomaceous earth under different temperatures. In:Lorini, I., Bacaltchuk, B., Beckel, H., Deckers, D., Sundfeld, E., P., d.S.J., Biagi, J.D., Celaro, J.C., Faroni,L.R.D.A., Bortolini, L.d.O.F., , Sartori, M.R., Elias, M.C., Guedes, R.N.C., da Fonseca, R.G., Scussel, V.M.(Eds), Proceedings of the Ninth International Working Conference on Stored Product Protection, 15-18October 2006, Campinas, Brazil, Brazilian Post-harvest Association, Campinas, Brazil, pp 804-810.

Lima, C.P.F.D. (1987). Insect pests and post-harvest problems in the tropics. *Insect Science and its Application.* 8: 673-676

Mamo, T. (2010). Selection for drought and bruchid resistance of common bean populations. *Dissertation for the Doctoral School of Crop Sciences*, University of Padova. Padova, Italy.

Mishili, F. J., A. Temu, J. Fulton, and J. Lowenberg-DeBoer (2011). Consumer Preferences as Drivers of the Common Bean Trade in Tanzania: A Marketing Perspective. *Journal of International Food & Agribusiness Marketing. 23:2, 110-127*

Moussa, B. (2006). Evaluating Impact Assessment of Cowpea Storage Technology. Master of Science thesis, Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA, 2006.

Mulungu, L.S., E.N. Luwondo, S. Reuben and R. Misangu (2007). Effectiveness of Local Botanicals as Protectants of Stored Beans (*Phaseolus vulgaris* L.) Against Bean Bruchid (*Zabrotes subfasciatus* Boh) (Genera: Zabrotes. Family: Bruchidae). *Journal of Entomology.* 4(3): 210-217.

Murdock, L.L. and R.E. Shade (1991). Eradication of cowpea weevil (Coleoptera: Bruchidae) in cowpea by solar heating. *Annual Reviews of Entomology.* 37: 228-231.

Murdock, L.L., D. Seck, G. Ntoukam, L. Kitch, R.E. Shade (2003). Preservation of cowpea grain in Sub-Saharan Africa- Bean/Cowpea CRSP contributions. *Field Crops Research.* 82: 169-178

Nichimi-Msolla, S. and R.N. Misangu (2002). Seasonal distribution of common bean (*Pasheolus vulgaris* L.) bruchid species in selected areas in Tanzania. *Proceedings from the Bean Seed Workshop of the Bean/Cowpea Collaborative Research Support Program- East Africa.* 12-14 January, 2002. Arusha, Tanzania

Ognakossan, K.E., K.E. Adabe, K. Hell, Y. Lamboni, and O. Coulibaly (2010). Use of PICS bags for the control of *P. truncatus* and *Dinoderus* spp. on stored cassava chips: First results. Poster presented during the 5th World Cowpea Conference, 27 September to 1 October 2010, Saly, Senegal.

Pachico, D. (1993). The deamdn for bean technology. *Trends in CIAT commodities 1993. Working Document No. 128.* pp. 60-74. Henry, G., ed. CIAT, Cali, Colombia.

Paul, U.V. (2007). Bean Pest Management in East Africa- A scientific evaluation of organic insect control practices used by Tanzanian farmers. *Dissertation for the degree of Doctor of Natural Sciences.* Swiss Federal Institute of Technology, No. 17528.

Paul, U.V., J.S. Lossini, P.J. Edwards, and A. Hilbeck (2009). Effectiveness of product from four locally grown plants for the management of *Acanthoscelides obtectus* (Say) and *Zabrotes subfasiatus* (Boheman) (both Coleoptera: Bruchidae) in stored beans under laboratory and farm conditions in Northern Tanzania. *Journal of Stored Products Research.* 45: 97-107

Quezada, M. Y., J. Moreno, M.E. Vázquez, M. Mendoza, A. Méndex-Albores, E. Moreno-Martínez (2006). Hermetic storage system preventing the proliferation of *Prostephanus truncatus* Horn and storage fungi in maize with different moisture contents. *Postharvest Biology and Technology.* 39: 321-326

Songa, J.M. and W. Rono (1998). Indigenous methods for bruchid beetle (Coleoptera: Bruchidae) control in stored beans (*Phaseolus vulgaris* L.). *International Journal of Pest Management.* 44(1): 1-4

Stephens, E.C. and C.B. Barrett. (2009). Incomplete credit markets and commodity marketing behavior. Cornell University Working Paper.

Velten, G., A.S. Rott, C. Cardona, and S. Dorn (2007). The inhibitory effect of the natural seed storage protein arcelin on the development of *Acanthoscelides obtectus. Journal of Stored Products Research.* 43: 550-557.

WHO (1992). *The Global Climate System. Climate System Monitoring Dec 1988 – May 1991.* pp. 73-74. WMO World Climate Data and Monitoring Program, United Nations Environment Program (UNEP), Nairobi, Kenya

Wortmann, C.S., R.A. Kirkby, C. Eledu, and D.J. Allen. (1998). *The Atlas of Common Bean in Africa*, CIAT, Cali, Colombia, October 1998.